FOREST GROVE OREGON

A place where families and businesses thrive.

CITY COUNCIL MEETING (ZOOM WEBINAR)

Monday, February 28, 2022
Community Auditorium, 1915 Main Street and Zoom Meeting (See Instructions Below)

PETER B. TRUAX, MAYOR

Malynda H. Wenzl, Council President
Donna Gustafson, Councilor
Kristy L. Kottkey, Councilor
Timothy A. Rippe, Councilor
Elena Uhing, Councilor
Mariana Valenzuela, Councilor

Zoom Webinar Link:
https://us06web.zoom.us/j/81734537842?pwd=ZCtXNjJQRi9mRExxeUhhL1R1WGpXZz09
Zoom Meeting ID: **817 3453 7842** *and Passcode:* **022422**

CITY COUNCIL WORK SESSIONS

No public comment will be taken. The Council will take no formal action.

5:30 [25 mins] **Solid Waste CEP Advisory Committee (CEPC) Meeting** (PPT)
Staff: Rebeka Andrade, Program Coordinator; and Paul Downey, Assistant City Manager/Finance Director

5:55 [55 mins] **Council Joint Work Session Planning Commission:** Forest Grove Water System Master Plan Part II (PPT)
Consultant: Brian Ginter, PE, Murraysmith
Staff: Gregory Robertson, Public Works Direction; Bryan Pohl, Community Development Director

6:50 [10 mins] **Council Recess**

CITY COUNCIL MEETING – 7:00 PM

A. 7:00 [5 mins] **Call to Order**

B. 7:05 [5 mins] **Public Comment:** Anyone wishing to speak to the City Council on an item not on the agenda or on the agenda and not scheduled for a public hearing may be heard. Please limit comments to two (2) minutes. All testimony is electronically recorded. Written comments may be submitted by 3:00 p.m. on the day of the meeting to *CityCouncilors@forestgrove-or.gov*. **Zoom Attendees:** Please use the "Raise Hand" option. Please introduce yourself and ask your question or provide your comments.

1. CC02-28-2022 Written Public Comment

C. 7:10 [5 mins] **Consent Agenda:** Items under the Consent Agenda are considered routine and will be adopted with a single motion, without separate discussion. Council members who wish to remove an item from the Consent Agenda may do so prior to the motion to approve the item(s). Any item(s) removed from the Consent Agenda will be discussed and acted upon following the approval of the remaining Consent Agenda item(s).

1. Approve City Council Work Session (Parks and Recreational Fee Schedule) Meeting Minutes of February 14, 2022.

2. Approve City Council Work Session (Council Goals & Objectives Refinement) Meeting Minutes of February 14, 2022.

3. Approve City Council Regular Meeting Minutes of February 14, 2022.

4. Accept Community Forestry Commission (CFC) Meeting Minutes of January 12, 2022.

5. Accept Library Commission (LC) Meeting Minutes of January 12, 2022.

6. Accept Parks and Recreation Commission (P&R) Meeting Minutes of December 15, 2021.

7. Accept Planning Commission (PC) Meeting Minutes of November 1, 2021.

8. Accept Sustainability Commission (SC) Meeting Minutes of November 18, 2021.

9. Endorse Liquor License Renewal Applications for Year 2022.

D. 7:15 [5 mins] **Additions/Deletions**

1. City Manager

2. Proposed by Councilors

E. 7:20 **Presentations:** Each Presenter is limited to ten (10) minutes to present, followed by five (5) minutes for questions and answers, unless additional time is granted by the presiding officer. The Council has reviewed each presentation, so highlight key points only. The Council will hold questions until the end. A two-minute reminder will be given to conclude remarks.

1. 7:20 [15 mins] **Family Justice Center of Washington County** (PPT)
Presenter: Rachel Francisca José Schutz, Executive Director

F. Public Hearings, Ordinances, and Resolutions

1. 7:35 (10 mins) PUBLIC HEARING
RESOLUTION NO. 2022-09 AMENDING FOREST GROVE PARKS AND RECREATION FEES AND CHARGES AND REPEALING RESOLUTION NO. 2021-26 AND PARKS AND RECREATION FEES AND CHARGES LISTED IN EXHIBIT 2 OF

RESOLUTION NO. 2021-27, EFFECTIVE APRIL 1, 2022
Staff: Anne Lane, Parks and Recreation Director; Paul Downey, Assistant City Manager/Finance Director

2. 7:45 (15 mins) PUBLIC HEARING
RESOLUTION NO. 2022-10 APPROVING SUBMITTAL OF NOTICE OF MEASURE FOR THE CITY OF FOREST GROVE, OREGON, FOR REPLACEMENT OF ITS LOCAL OPTION LEVY AT THE MAY 17, 2022, ELECTION
Staff: Paul Downey, Assistant City Manager/Finance Director

3. 8:00 [10 mins]
RESOLUTION 2022-11 ADOPTING REVISION TO LIGHT AND POWER DEPARTMENT LINE EXTENSION POLICY ALLOWING A TEMPORARY MATERIALS SURCHARGE TO THE SUBDIVISION PER-LOT FEE
Staff: Keith Hormann, Light and Power Director

4. 8:10 [10 mins] PPT
RESOLUTION NO. 2022-12 AUTHORIZING IMPLEMENTATION OF A BUSINESS INCENTIVE PROGRAM FOR VACANT SPACE AND ESTABLISHING PROGRAM REQUIREMENTS
Staff: Brenna Fulks, Economic Development Coordinator

5. 8:20 [5 mins] **Council Recess**

6. 8:25 [20 mins] PPT
RESOLUTION NO. 2022-13 ACCEPTING EAST FOREST GROVE SAFETY IMPROVEMENT PLAN FOR TUALATIN VALLEY HIGHWAY (OREGON HIGHWAY 8) AND AUTHORIZING CITY MANAGER TO ADMINISTER THE PLAN
Staff: Dan Riordan, Senior Planner; Bryan Pohl, Community Development Director

7. 8:45 (10 mins)
RESOLUTION NO. 2022-14 AUTHORIZING THE DEVELOPMENT SERVICE ANNEX/CITY HALL REMODEL PROJECT AND COMMITTING ADDITIONAL FUNDING SOURCES REQUIRED TO CONSTRUCT THE PROJECT
Staff: Paul Downey, Assistant City Manager/Finance Director

8. 8:55 [10 mins]
RESOLUTION NO. 2022-15 OF THE CITY OF FOREST GROVE CITY COUNCIL ADOPTING 2022 CITY COUNCIL GOALS AND OBJECTIVES
Staff: Jesse VanderZanden, City Manager

G. 9:05 [25 mins] **Council Communications:** Please limit remarks to three (3) minutes per person. A brief summary of matters of interest to the Council and to present Boards and Commissions liaison reports. (Council Rules Section 6.3)

1. Councilor Reports

2. City Manager's Report

3. Mayor's Report

H. 9:30 **Adjournment**

*The public can observe the meetings **LIVE** on **Zoom** Webinar or on Tualatin Valley Community Television (TVCTC) Government Access Programming or **LIVE Channel** 30 on their website: http://201.71.205.11/CablecastPublicSite/?channel=15.*

***ADA Notice:** In accordance with the Americans with Disabilities Act (ADA), the City of Forest Grove will make reasonable accommodations for participation in the meeting. Requests for assistance can be made by contacting the City Recorder's Office, aruggles@forestgrove-or.gov, 503-992-3235, at least 48-hours in advance of the meeting.*

City of Forest Grove
Water System Plan Update

City Council and Planning Commission Work Session
February 28, 2022

PRESENTED BY

Brian Ginter, PE, ***Murraysmith***

Greg Robertson, ***City of Forest Grove***

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murraysmith

City of Forest Grove
Water System Plan Update

City Council and Planning Commission Work Session
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Purpose of Water System Plan

- Planning Resource for City Staff and Council
- Document System History and Components
- Outline plan for system improvements
- Show financial impact of Capital Improvement Program
- Meet Regulatory Requirements

Water System Plan Contents

Executive Summary

1 Introduction and Existing Water System

2 Water Requirements

3 Planning and Analysis Criteria

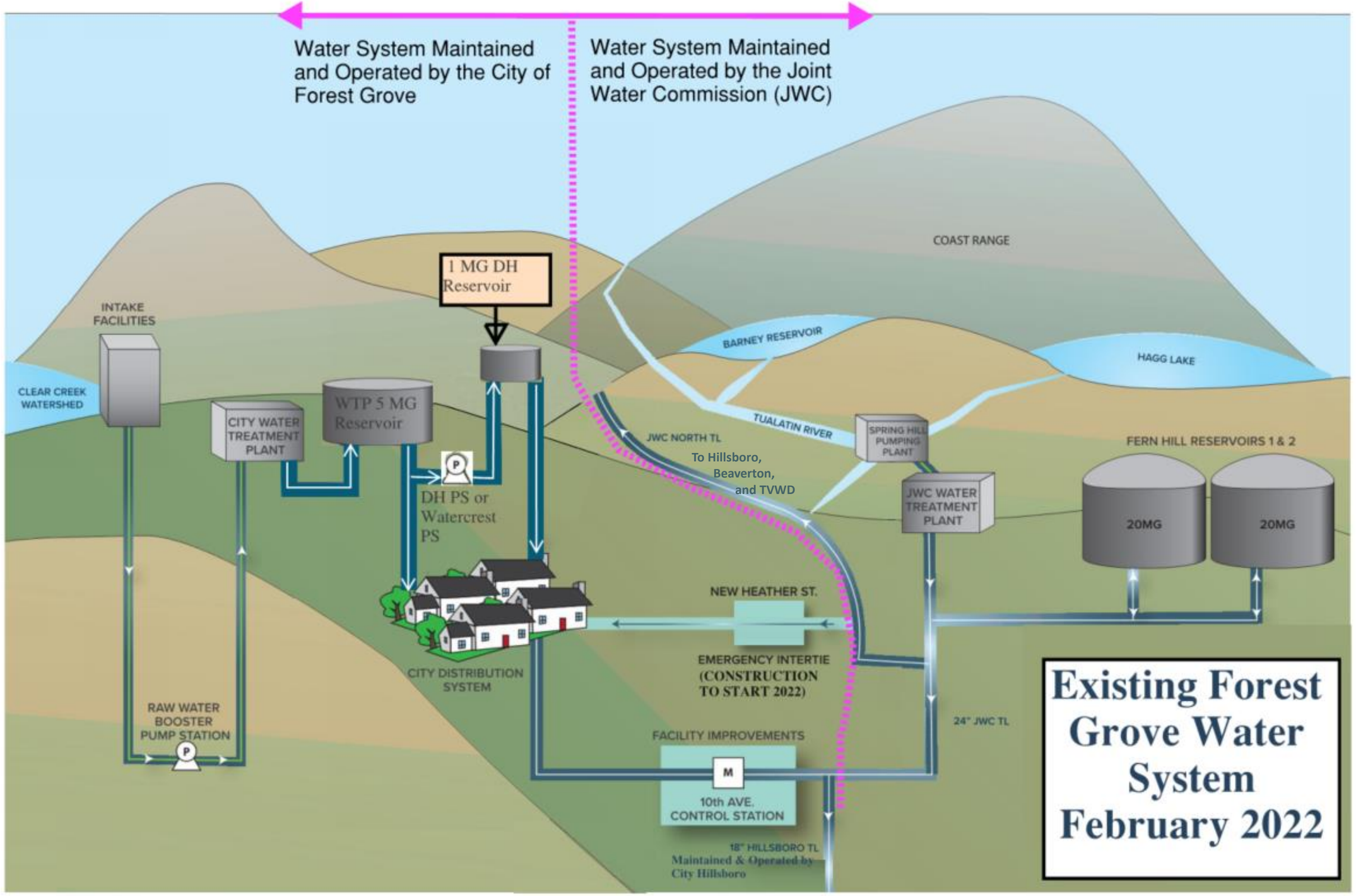
4 Water Supply Analysis

5 Distribution System Analysis

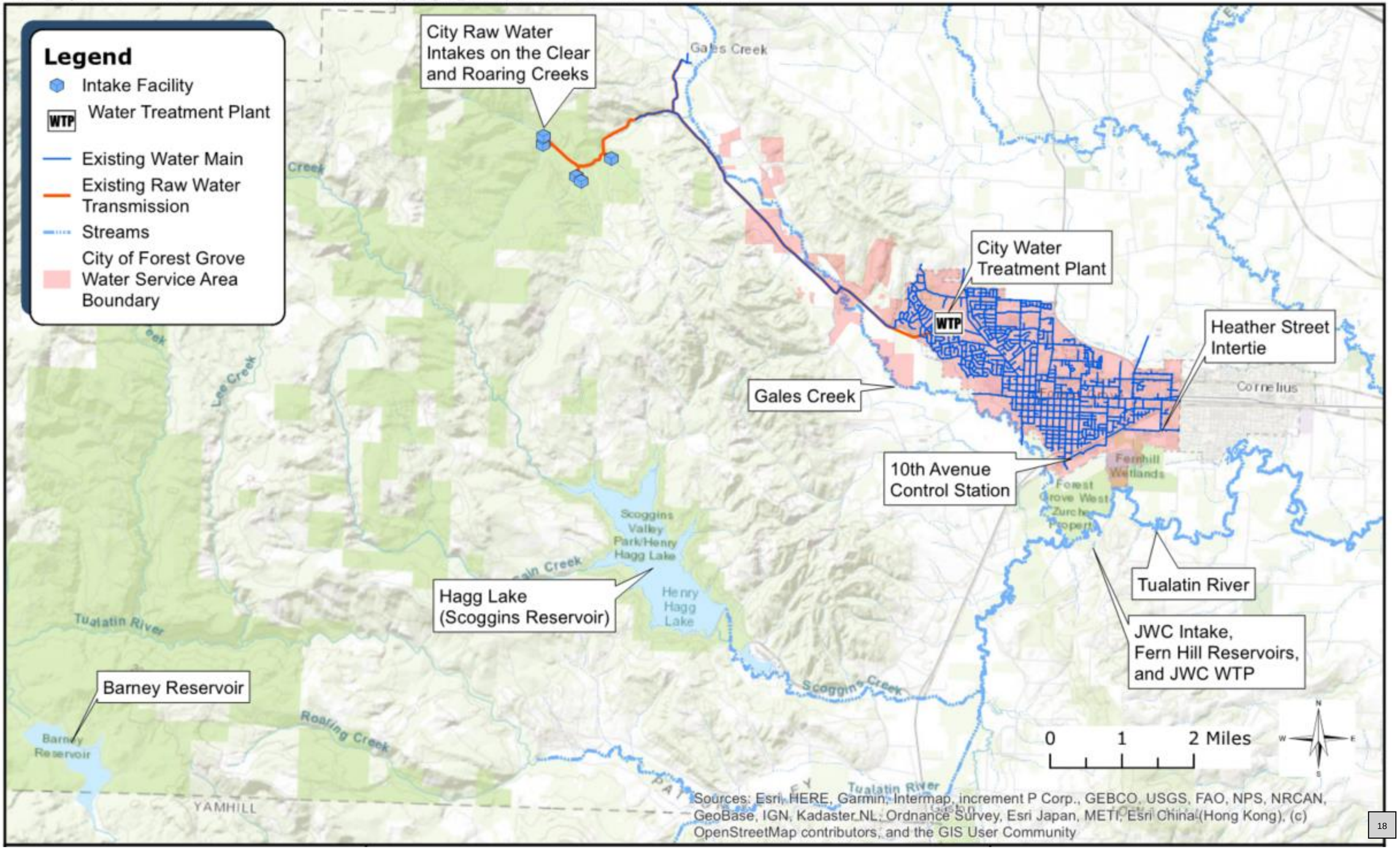
6 Seismic Resiliency Plan Summary

7 Capital Improvement Program

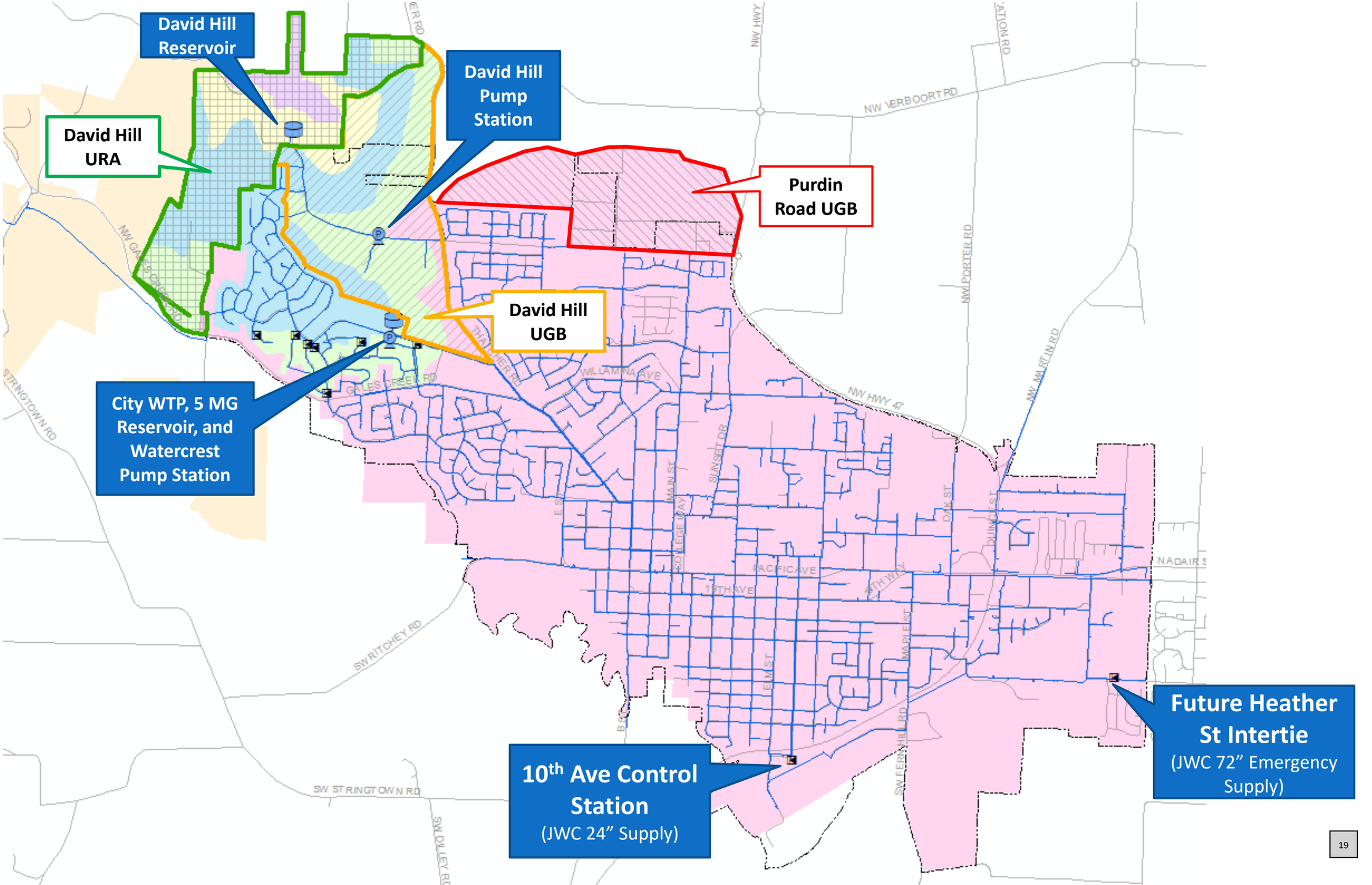
Description of Water System



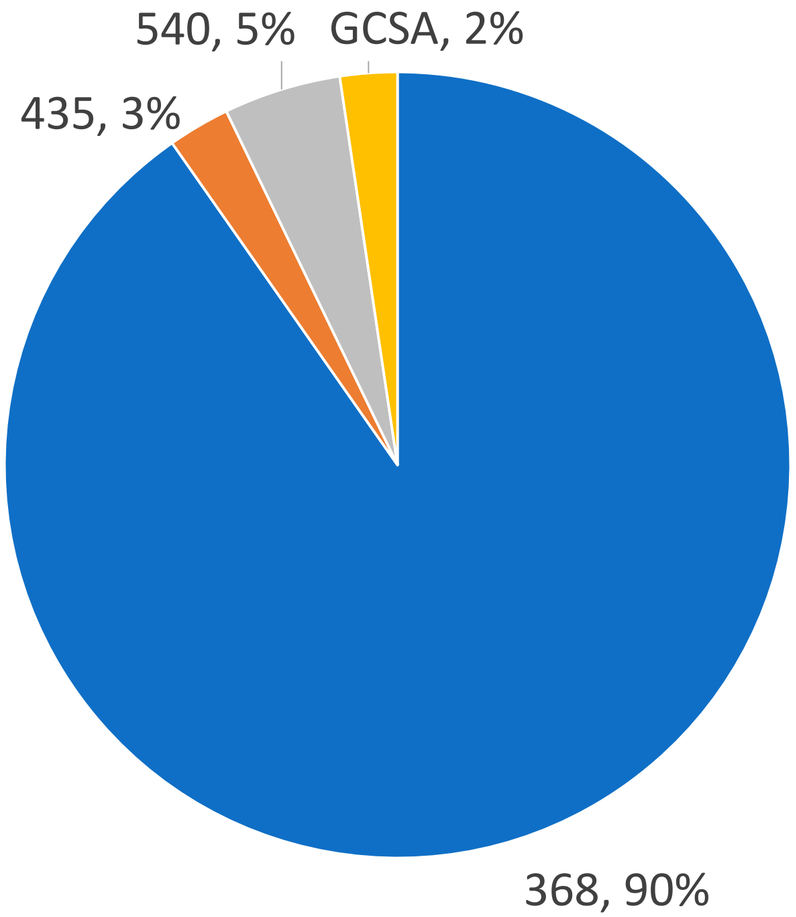
Description of Water System



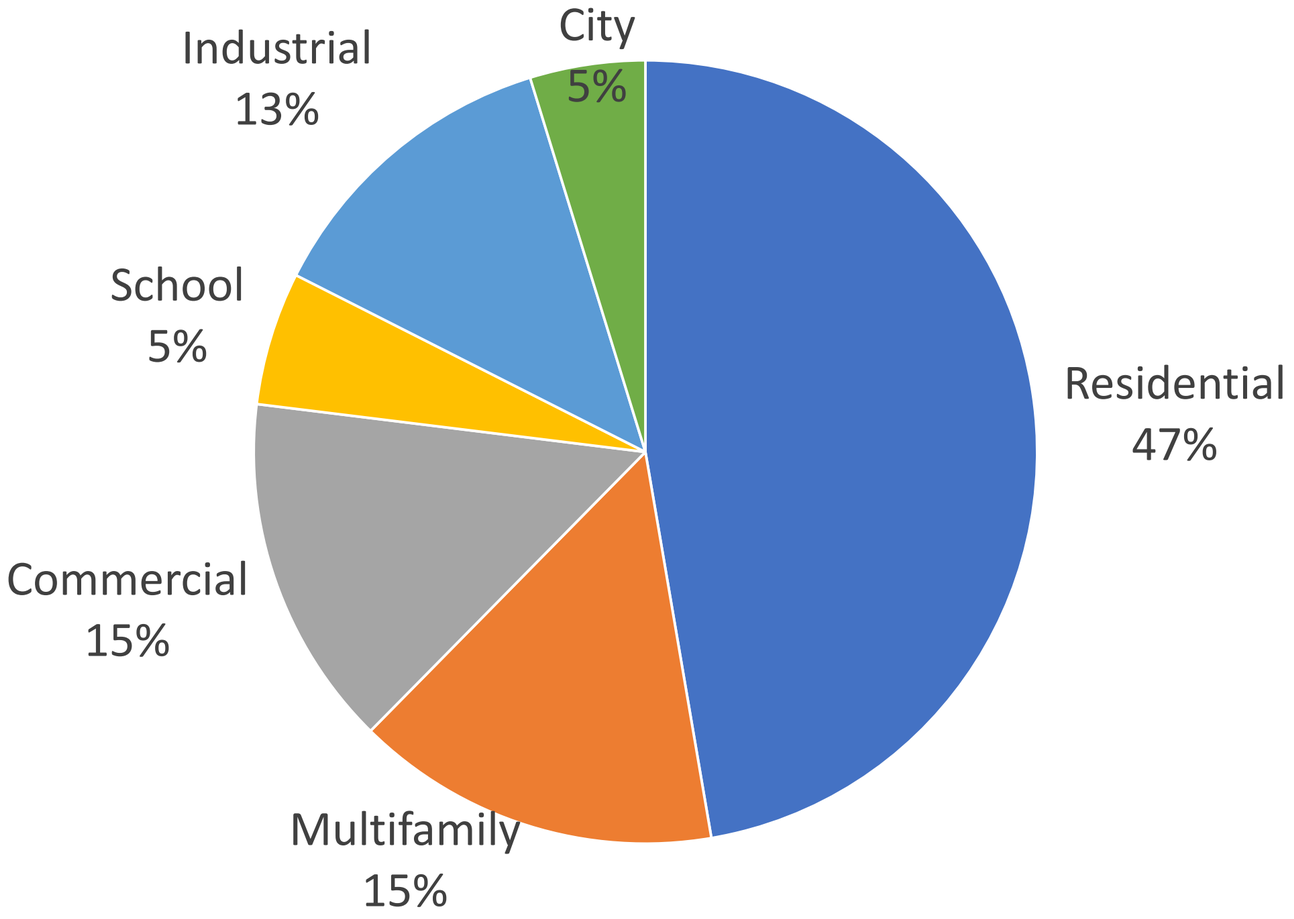
Description of Water System



Historical Demands (2018-2020)



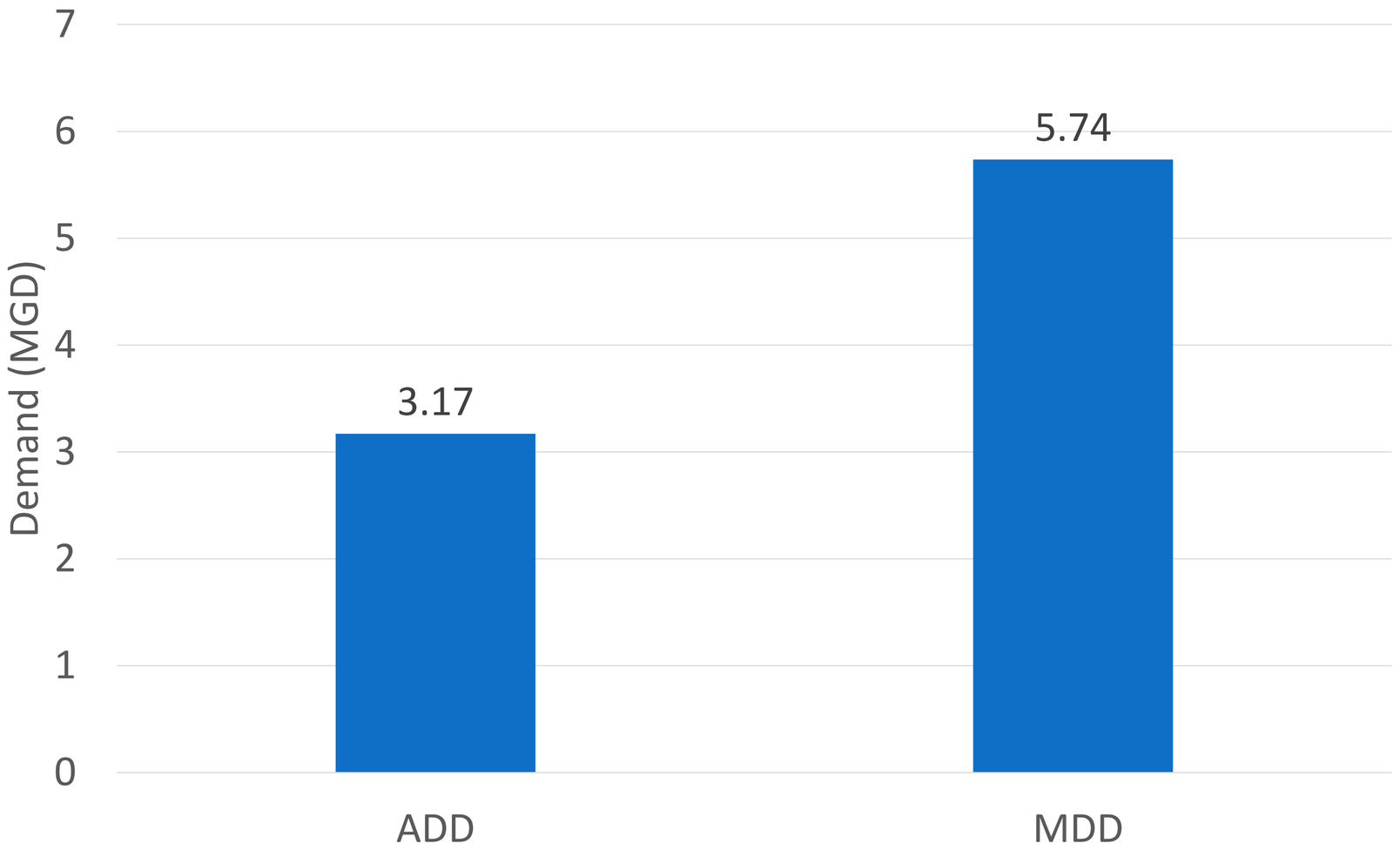
ADD by Pressure Zone



ADD by Customer Type

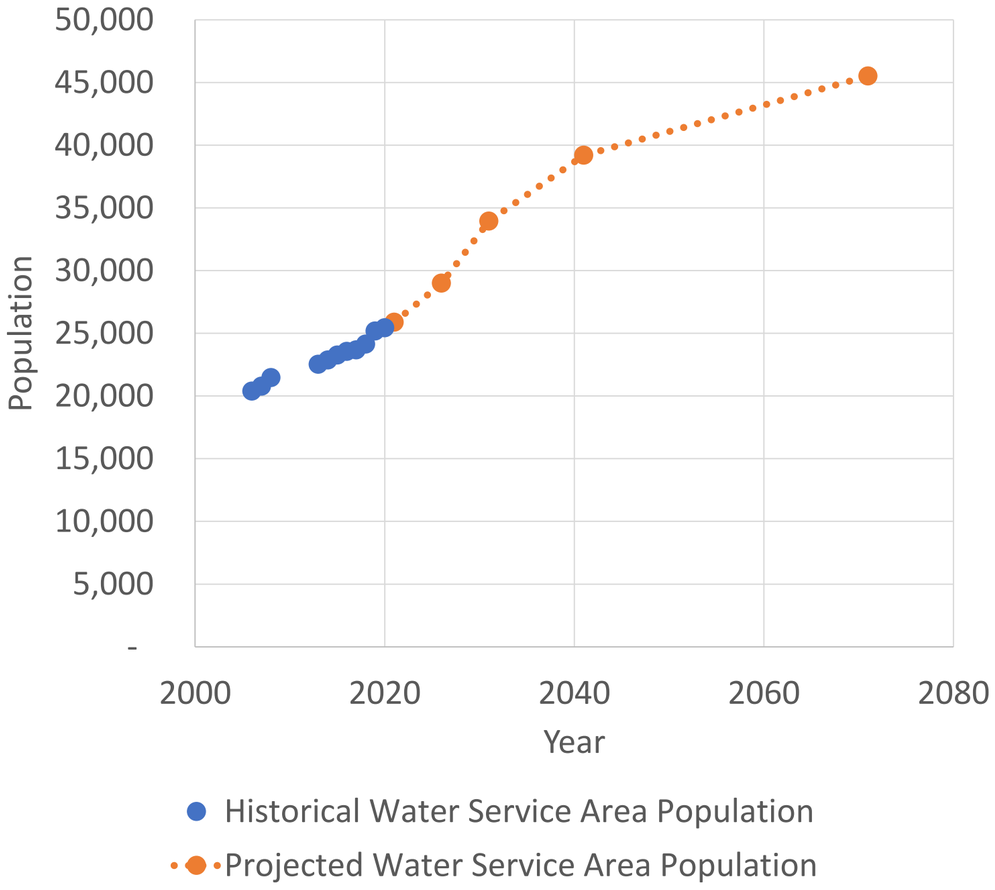
ADD= Average Day Demand

Historical Demands (2018-2020)

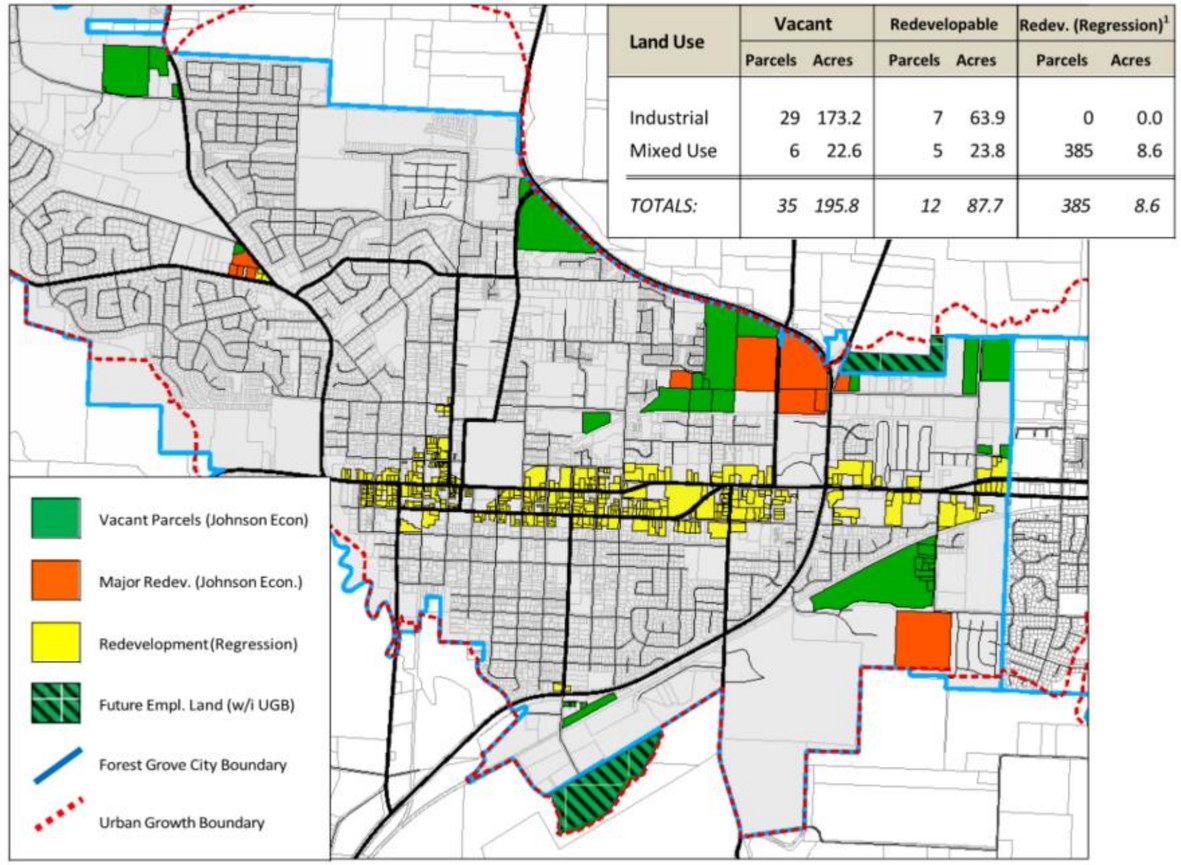


ADD= Average Day Demand
MDD = Max Day Demand

Planning Data and Projections



Population Projections

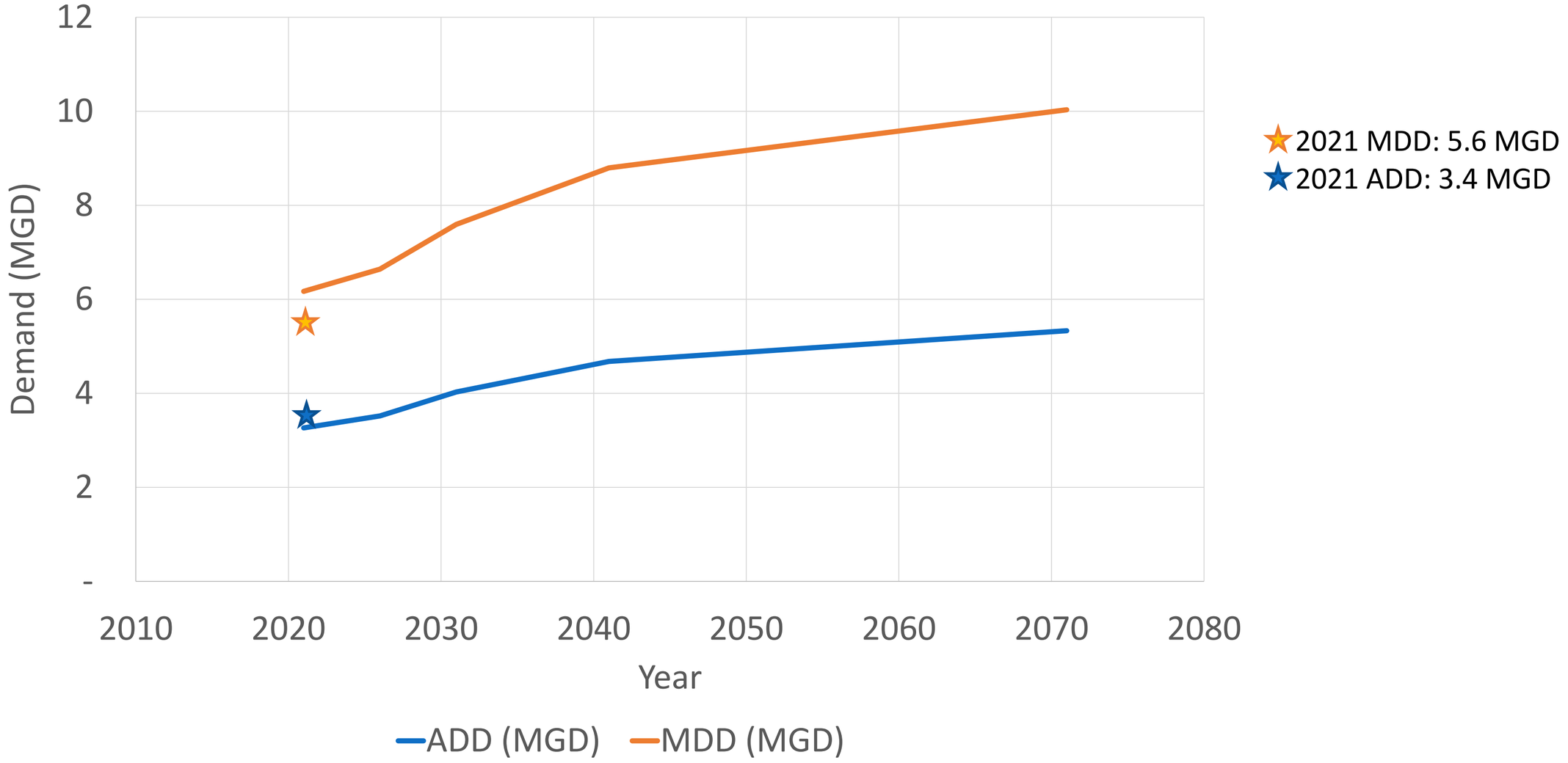


Land Use	Vacant		Redevelopable		Redev. (Regression)[1]	
	Parcels	Acres	Parcels	Acres	Parcels	Acres
Industrial	29	173.2	7	63.9	0	0.0
Mixed Use	6	22.6	5	23.8	385	8.6
TOTALS:	*35*	*195.8*	*12*	*87.7*	*385*	*8.6*

Source: Metro, City of Forest Grove, Johnson Economics

Non-Residential Projections

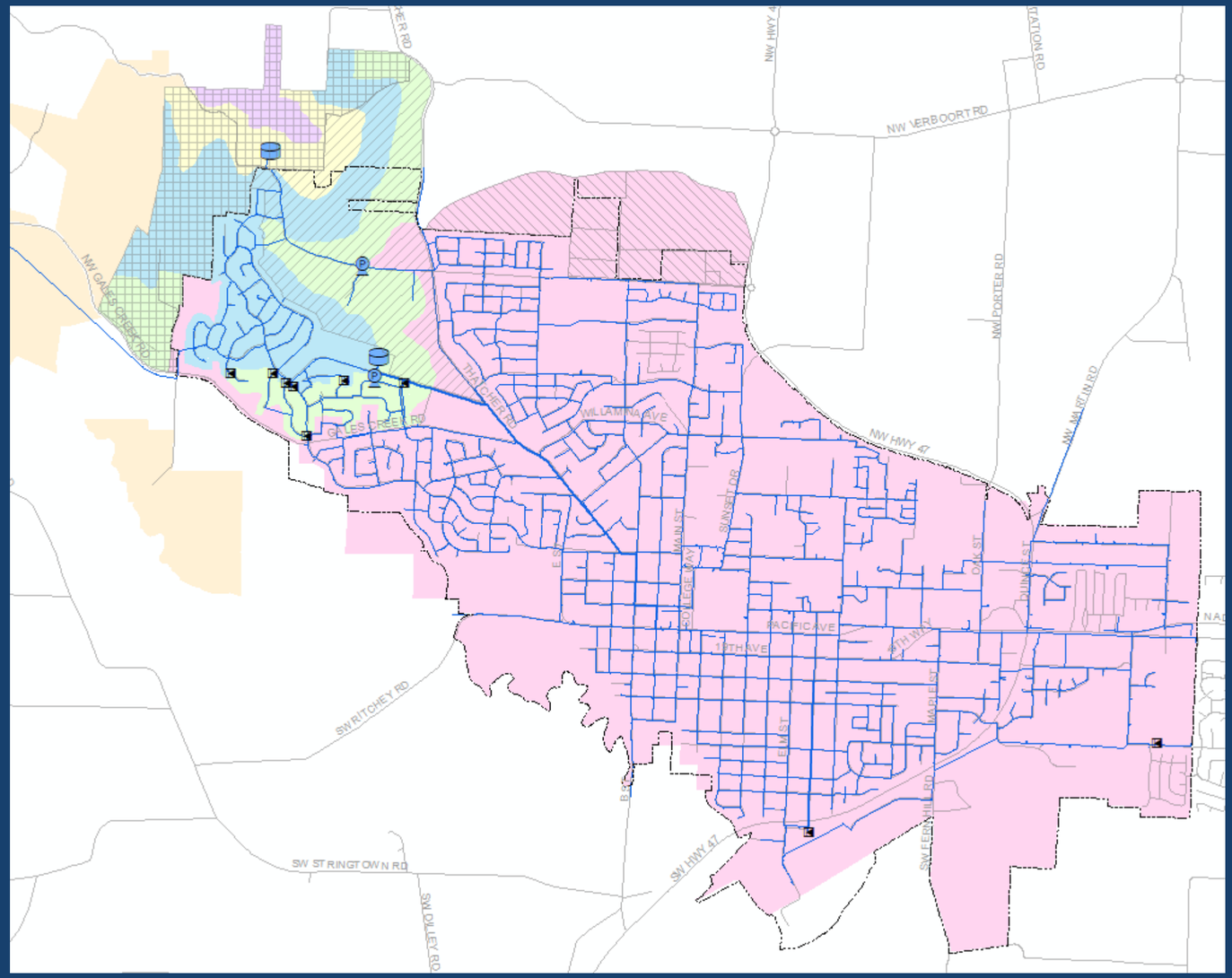
Demand Projections

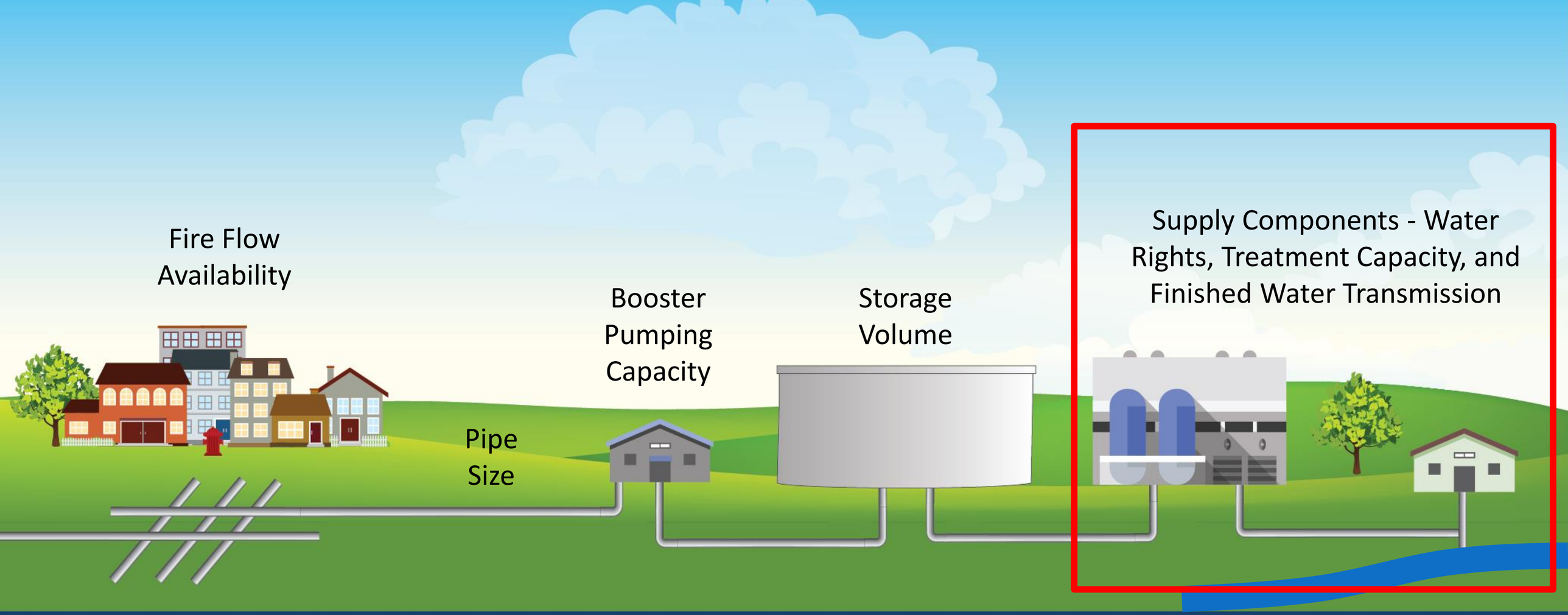


ADD= Average Day Demand
MDD = Max Day Demand

System Analysis

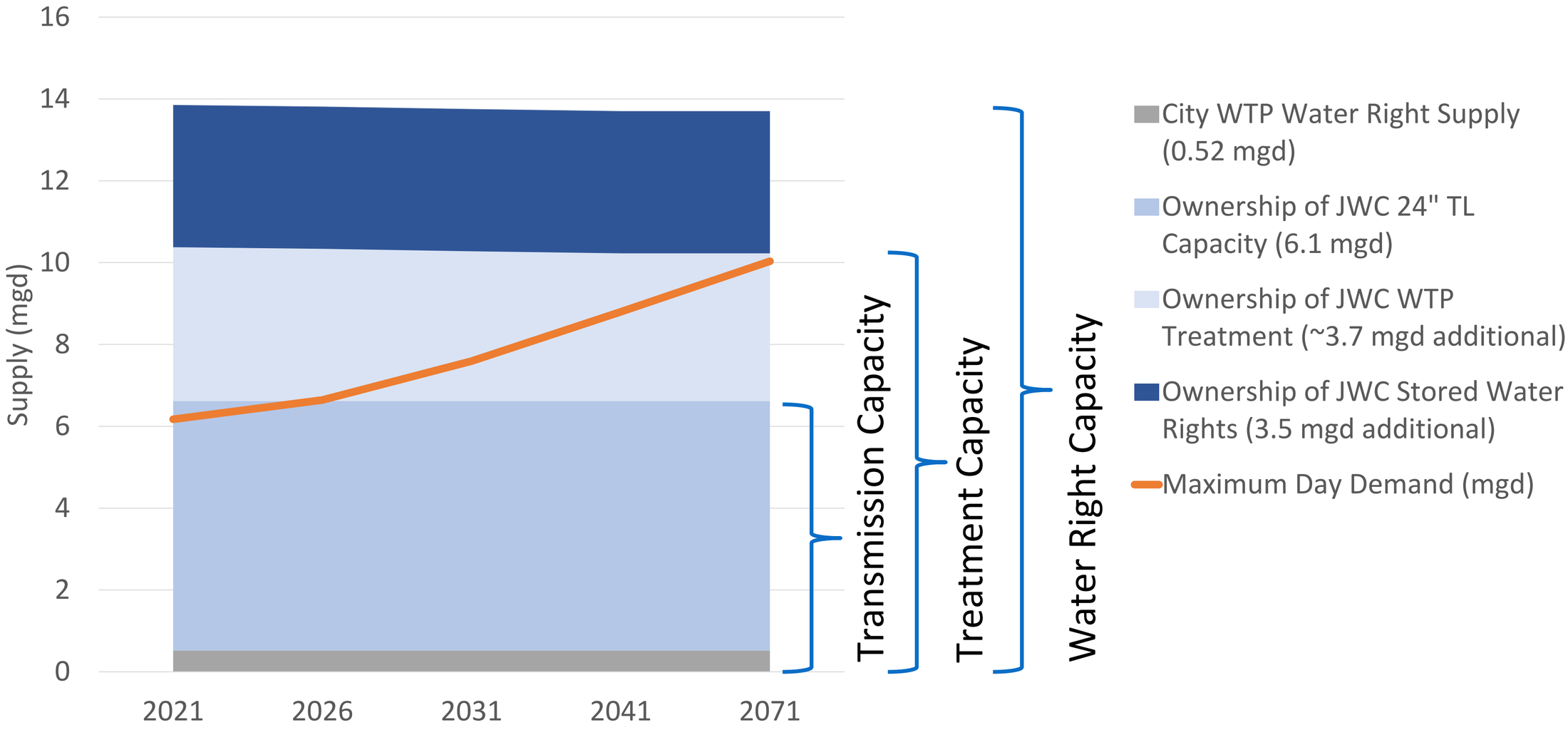
- Supply
  - City
    - Water Rights
    - Raw Water Transmission
    - WTP Capacity
  - JWC
    - Water Rights
    - WTP Capacity
    - Finished Water Transmission
- Distribution
  - 3 Main Pressure Zones
  - 2 Storage Reservoirs
  - 2 Pump Stations



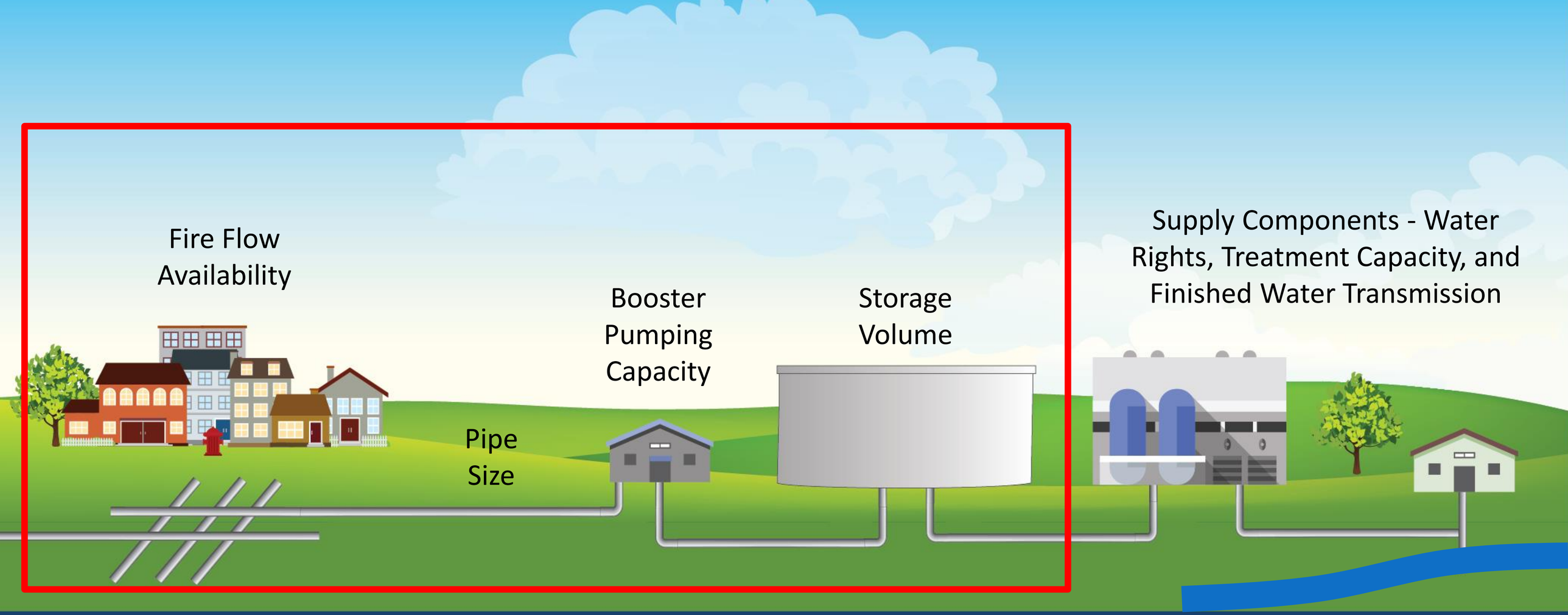


Water System Components Analyzed

Water Supply Analysis – Max Demand



MGD = Million Gallons per Day



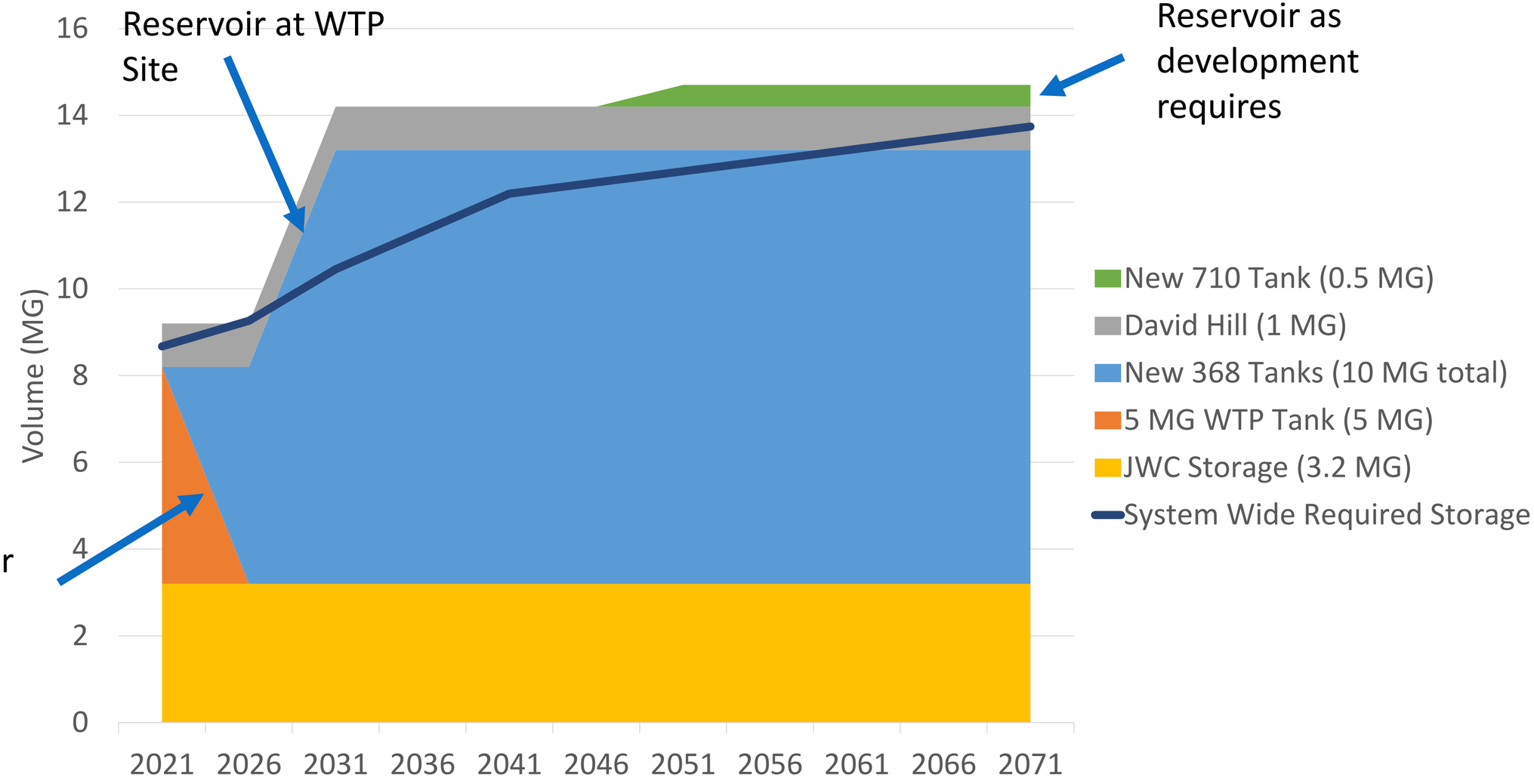
Water System Components Analyzed

Storage Analysis

Second 5 MG Reservoir at WTP Site

New 0.5 MG 710 Reservoir as development requires

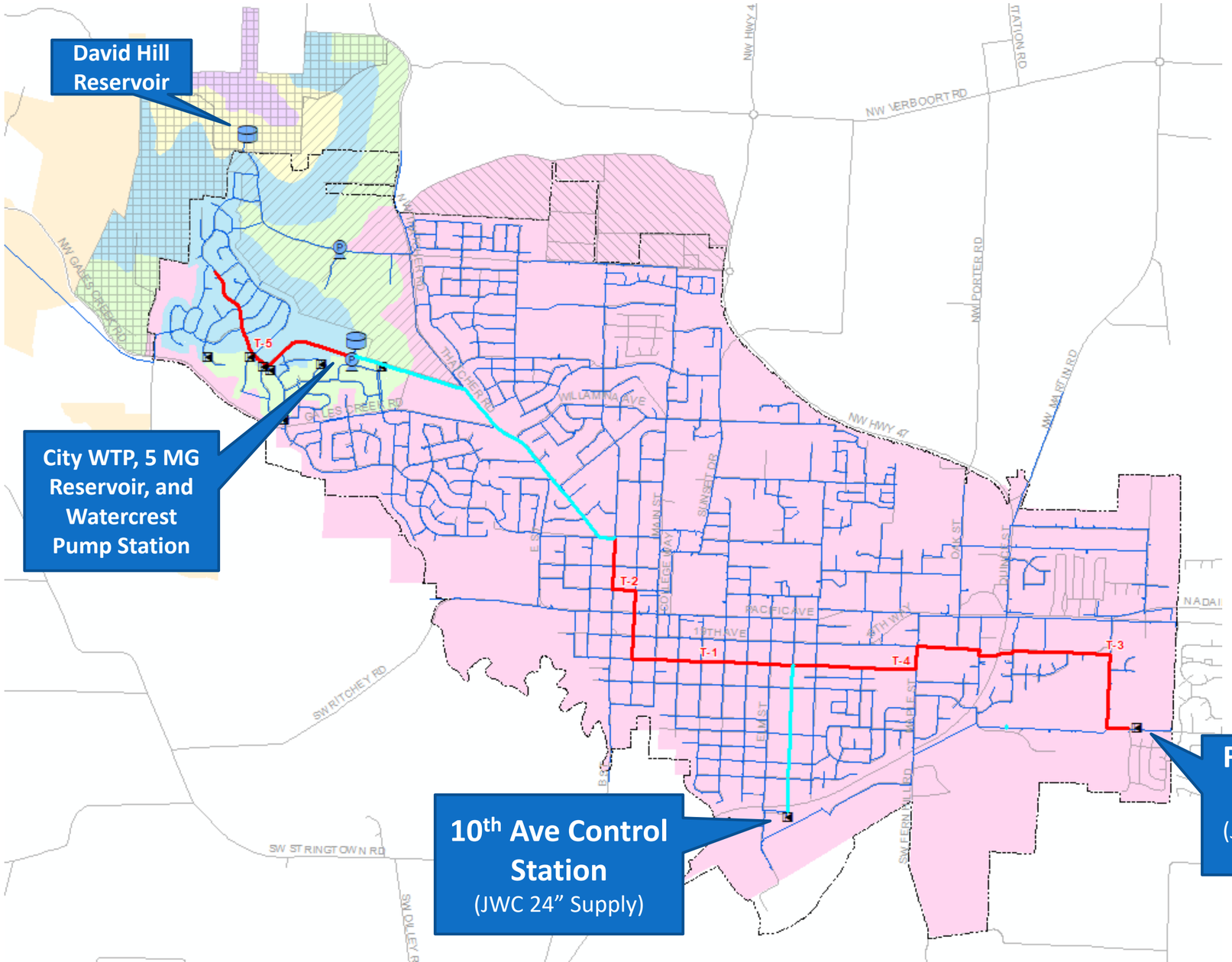
5 MG Reservoir Replacement



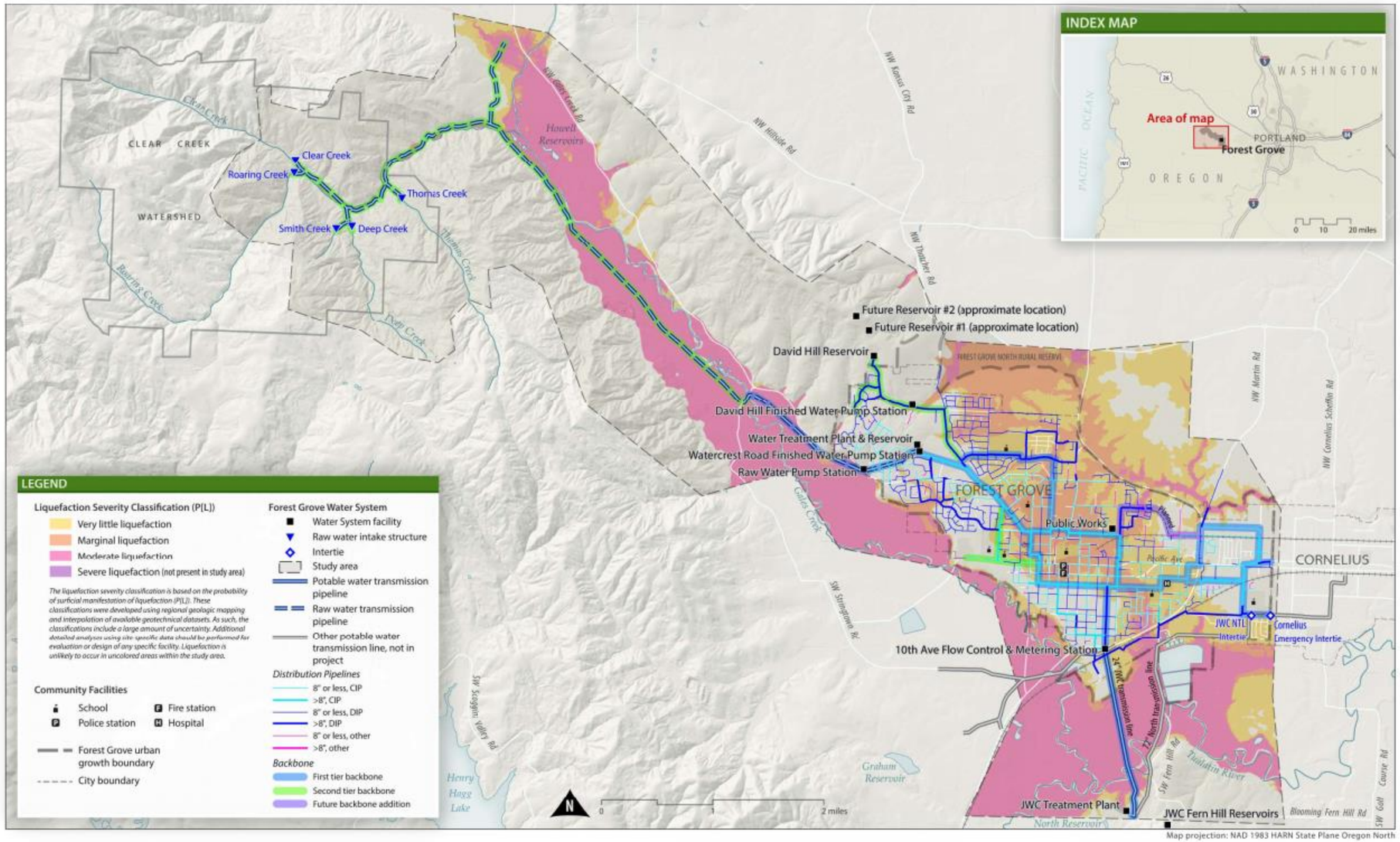
System Transmission

Existing 20-24”

Proposed Upsized Transmission



Seismic Analysis



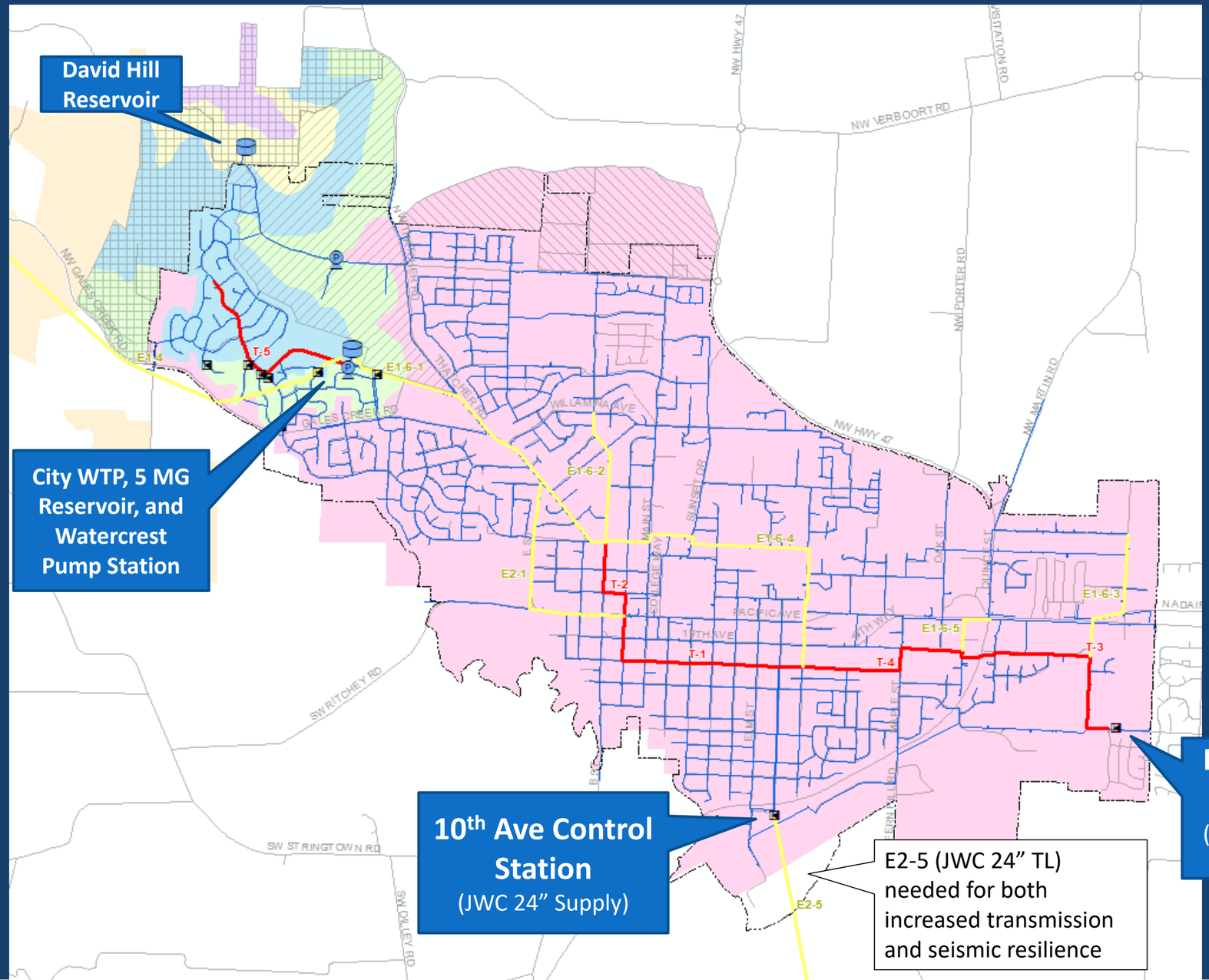
InfraTerra

Liquefaction Susceptibility for M9 CSZ Earthquake
Water Transmission and Distribution System

CITY OF FOREST GROVE WATER SYSTEM SEISMIC RESILIENCY PLAN
Plate 9
OCT 2018

Seismic Analysis

- Proposed Seismic Improvements
- Proposed Upsized Transmission (may also be concurrent with proposed seismic improvements)



Capital Improvement Program Goals



Improve Existing System



Provide for Development

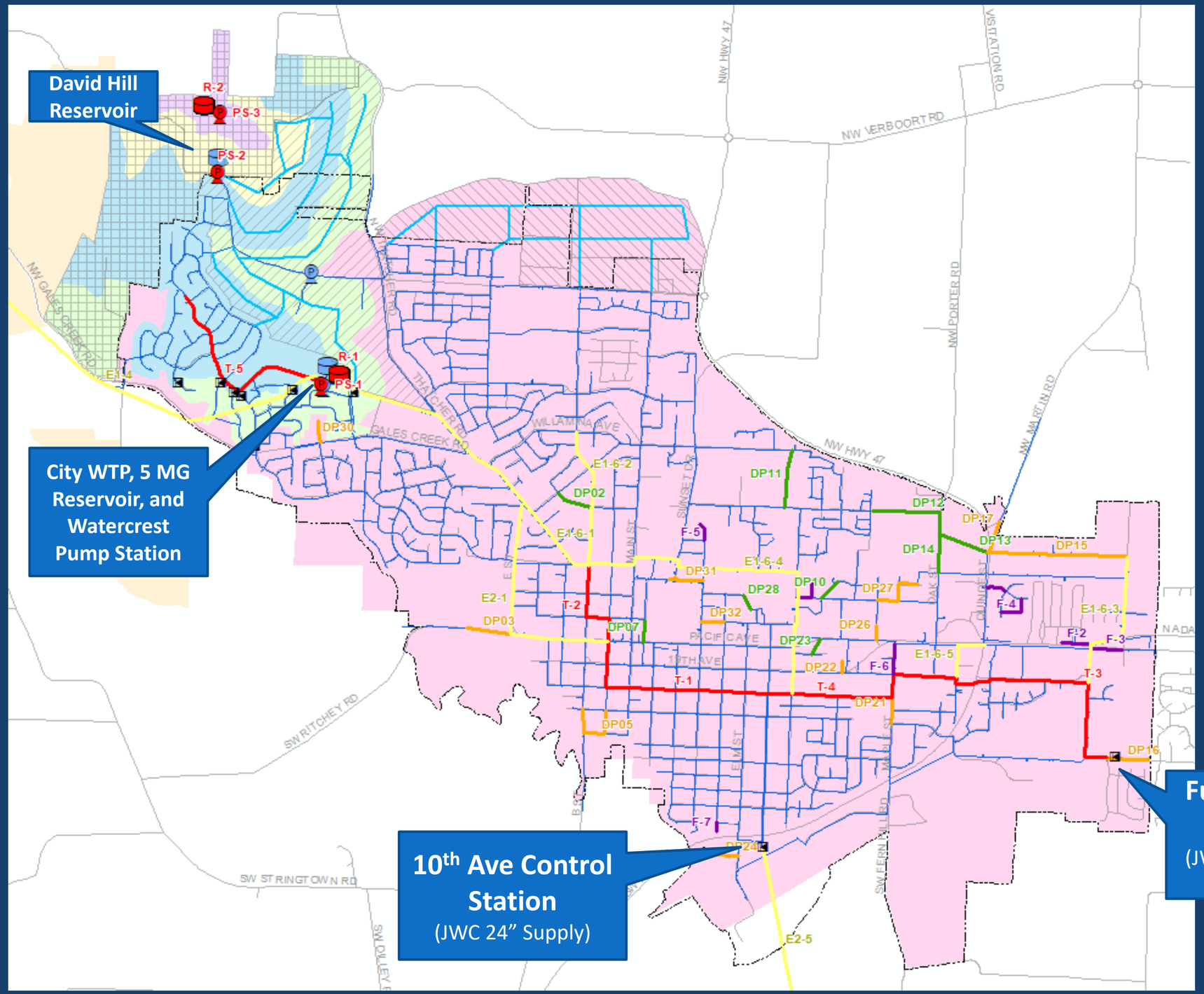


Seismic Preparation

Capital Improvement Program Areas of Focus

Project Type	0-5 Years	6-10 Years	11-20 Years	20-Year Total
Supply	$2,595,000	$-	$7,640,000	**$10,235,000**
Storage Reservoirs	$11,300,000	$11,300,000	$1,000,000	**$23,600,000**
Pump Stations	$2,100,000	$-	$850,000	**$2,950,000**
Piping Improvements	$7,840,000	$5,040,000	$8,210,000	**$21,090,000**
Seismic Improvements	$22,047,500	$50,000	$4,100,000	**$26,197,500**
Planning	$50,000	$300,000	$300,000	**$650,000**
TOTAL	**$45,932,500**	**$16,690,000**	**$22,100,000**	**$84,722,500**

Capital Improvement Program



- Seismic
- Transmission
- Fire Flow
- Projects Identified in Prior Plan
- System Connections
- New Distribution



Replace 5 MG Reservoir

Replace aging infrastructure, increase storage capacity, improve seismic resiliency



Increase Transmission of Finished Water from JWC

Increase capacity, improve seismic resiliency



Improve System Transmission

Increase capacity and system resiliency, improve fire flow deficiencies, improve seismic resiliency

Key CIP Projects

Summary

System currently adequately provides for existing residential, commercial, and industrial customers.

Investment is required to provide for future growth.

Additional investment is important to plan for seismic and emergency conditions

The proposed CIP will help the City build a more resilient system.

NEXT STEPS

- Legislative process:
  - Submit Draft for State Approval
  - Meet with Planning Commission
  - First/Second Reading at City Council
  - Approve Water Master Plan and Include in City Comprehensive Plan
- Begin Water Rate/SDC Update



Questions?

FOREST GROVE OREGON

A place where families and businesses thrive.

FINAL REVIEW

murraysmith



CITY OF FOREST GROVE

Water System Master Plan

February 2022

Water System Master Plan

City of Forest Grove

February 2022

FINAL REVIEW DRAFT

Murraysmith

888 SW 5th Avenue
Suite 1170
Portland, OR 97204

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Acronyms & Abbreviations

A	
AACE	Association for the Advancement of Cost Engineering International
AAGR	average annual growth rate
AC	asbestos cement
ADD	average daily demand
AWWA	American Water Works Association
C	
CCI	Construction Cost Index
CCP	concrete cylindrical pipe
Census	United States Census Bureau
CIP	Capital Improvement Program
City	City of Forest Grove
CSZ	Cascadia Subduction Zone
CSZE	Cascadia Subduction Zone Earthquake
CWS	Clean Water Services
D	
D/DBPR	Disinfectants and Disinfection Byproducts Rule
DBP	Disinfection Byproducts
DOGAMI	Department of Geology and Mineral Industries
DWS	Drinking Water Services
E	
EMAC	Emergency Management Assistance Compact
ENR	Engineering News-Record
EPA	Environmental Protection Agency
ES	emergency storage
F	
FEMA	Federal Emergency Management Agency
FS	fire storage
G	
GCSA	Gales Creek Service Area
GIS	geographic information system
Gpcd	gallons per capita per day
Gpm	gallons per minute
GSI	GSI Water Solutions, Inc.
H	
HAA5	Haloacetic Acids
HB	(Oregon) House Bill

HGL	hydraulic grade line
I	
IGA	intergovernmental agreement
ISO	Insurance Services Office
J	
JWC	Joint Water Commission
L	
LF	linear feet
LOS	level of service
M	
M9	Magnitude 9.0
MCL	maximum annual average level
MDD	maximum day demand
mgd	million gallons per day
MG	million gallons
mg/L	miligrams per liter
N	
NMU	neighborhood mixed-use (zoning)
NTL	North Transmission Line
O	
OAR	Oregon Administrative Rule
ODOT	Oregon Department of Transportation
OFC	Oregon Fire Code
OHA	Oregon Health Authority
OPSC	Oregon Plumbing Specialty Code
ORP	Oregon Resilience Plan
ORWARN	Oregon Water/Wastewater Agency Response Network
OS	operational storage
OSSPAC	Oregon Seismic Safety Policy Advisory Commission
P	
PF	peaking factor
pH	hydrogen potential
PHD	peak hour demand
PGA	peak ground acceleration
PGD	permanent ground deformation
PGV	peak ground velocity
POD	point of diversion
PPC	Public Protection Classification
PRV	pressure reducing valve
PS	Pump Station
psi	pounds per square inch
PSU PRC	Portland State University Population Research Center

PVC	polyvinyl chloride
R	
RLIS	Regional Land Information System
RWPC	Regional Water Providers Consortium
RWTM	Raw Water Transmission Main
S	
SCADA	supervisory control and data acquisition
SDCs	system development charges
SRP	Seismic Resilience Plan
T	
TL	Transmission Line
TTHM	Total Trihalomethanes
TVID	Tualatin Valley Irrigation District
TVWD	Tualatin Valley Water District
U	
UGB	urban growth boundary
URA	Urban Reserve Area
USGS	United Stated Geological Survey
V	
VFDs	variable frequency drives
W	
WMCP	Water Management and Conservation Plan
WSMP	Water System Master Plan
WTP	water treatment plant

Executive Summary

Executive Summary

Introduction

The purpose of this Water System Master Plan (WSMP) is to perform an analysis of the City of Forest Grove's (City's) water system and:

- Document water system upgrades, changes, and growth since the 2010 *Water Master Plan.*
- Estimate future water requirements including potential water system expansion areas.
- Document the City's recent water system seismic resilience evaluation.
- Identify deficiencies and recommend water facility improvements that correct deficiencies and provide for growth.
- Provide a recommended, prioritized Capital Improvement Program (CIP) for the water system.
- Comply with water system master planning requirements for Public Water Systems established under Oregon Administrative Rules (OAR).

Water System Overview

Service Area

The City provides finished water to approximately 26,000 residents through approximately 6,800 residential, commercial, industrial, and municipal service connections. The current service area includes all areas within the existing city limits and historic customers located outside the Urban Growth Boundary (UGB) along Gales Creek, Stringtown Road, Oppenlander Lane, and Martin Road. The study area of this planning effort is the current UGB, including the David Hill and Purdin Road areas. See **Figure 1-1** in **Section 1** for a map of the service area.

Supply

The City can source water from either City supply or Joint Water Commission (JWC) supply. Recently, approximately 40% of the City's annual supply has come from the JWC and 60% from the City. However, supply from either source is varied seasonally so that in the wet winter months, almost all supply is provided by the City and in the dry summer months, almost all supply is provided by the JWC.

The City owns and operates a water treatment plant (WTP) which treats water from the Clear Creek watershed and supplies finished water at the City's 5 MG Reservoir. The JWC treats Tualatin River raw water and supplies finished water to the City at the 10th Avenue Control Station. Supply from both the Clear Creek watershed and the Tualatin River is limited in the dry season due to in-stream flow requirements. The City WTP is typically reduced to a single older water right, while the JWC WTP can supplement in stream flows with water stored in local impoundments, Barney Reservoir and Hagg Lake (Scoggins Reservoir). Water is released from these impoundments into the Tualatin Reservoir and withdrawn at the JWC intake to be treated and supplied by the JWC to the City and other consumers. The City has one emergency intertie with the City of Cornelius and is preparing to construct an emergency connection to the JWC's 72-inch North Transmission Line at Heather Street. See **Figure 1-2** in **Section 1** for a map of the supply system.

Distribution System

The City's existing distribution system is divided into four pressure zones, with two additional pressure zones proposed for future service. Pressure zones are usually defined by ground topography and designed to provide acceptable pressures to all customers in the zone. Zones are designated by hydraulic grade line (HGL) which are set by overflow elevations of water storage reservoirs or outlet settings of pressure reducing facilities serving the zone. An HGL approximately 100 feet above the elevation of a service connection results in a pressure of approximately 43 pounds per square inch (psi). Pressure zone boundaries are further refined by street layout and specific development projects.

Within each pressure zone, storage reservoirs provide gravity supply to looped distribution piping serving customers throughout the service area. The water system has 6.0 million gallons (MG) of available storage within the system and an addition 3.2 MG of available storage in the JWC Fern Hill Reservoirs, used for water system equalizing (fluctuations in demand throughout the day), fire suppression, and emergency conditions. See **Figure 1-3** and **Appendix A** for a system hydraulic schematic and detailed system map.

Water Demand

Water demand refers to all water required by the system including residential, commercial, industrial, and irrigation uses and unmetered use such as hydrant flushing, firefighting, or leakage. Demands are described using water metrics including average day demand (ADD) and maximum day demand (MDD).

Future expansion of the City's water service area will include development in the Purdin Road and David Hill Planning Areas within the UGB, and the David Hill Urban Reserve Area (DHURA), as well as infill development within the existing City limits. The forecasted future water demands are calculated based on the historical system demand and forecasted demands based on zoning of future development areas.

Population growth within the water service area was projected based on population forecasts from the Population Research Center (PRC, Portland State University, 2019) and estimates from prior City efforts for specific planning areas. Non-residential demand growth was based on the 2019 Economic Opportunity Analysis (Johnson Economics). Historical demand data was used to forecast water use per residential customer as well as water use for other customer categories including commercial, industrial, and irrigation accounts. MDD was projected based on the historic ratio of MDD to ADD, also called a peaking factor, by customer class. Both ADD and MDD were forecasted through 2071, shown for the planning years of 2026, 2031, 2041, and 2071 in Error! Reference source not found.. The forecasted time steps support identification of existing and future system deficiencies, prioritization of CIP projects to support development and growth, and sizing of future infrastructure to serve the long-term needs of the City.

Table ES-1-1 | Projected Water Demand

Year	ADD (mgd)	MDD (mgd)
2021	3.27	6.17
2026	3.52	6.64
2031	4.03	7.59
2041	4.68	8.80
2071	5.33	10.03

Analysis Criteria

Performance guidelines and system criteria are used with water demands presented in **Table ES-1-1** to assess the water distribution system's ability to provide adequate water service under existing conditions and to guide improvements needed to provide for future water needs. Criteria are established through a review of City design standards, state requirements, American Water Works Association (AWWA) acceptable practice guidelines, Ten States Standards, the Washington Water System Design Manual, and practices of other water providers in the region.

Water Supply

The City should plan for adequate peak season (summer) supply capacity to meet the future MDD projections in each of the following: raw water source, raw water transmission, treatment, and finished water transmission. During the off-peak season, the supply system must be capable of providing off-peak season demand.

Service Pressure

The acceptable service pressure range under ADD conditions is 40 to 100 psi. Per the *Oregon Plumbing Specialty Code*, maximum service pressures must not exceed 80 psi without individual PRVs to regulate pressure to less than 80 psi. During a fire flow event or emergency, the minimum service pressure is 20 psi, which meets requirements by Oregon Health Authority Drinking Water Services regulations.

Storage Capacity

Adequate storage capacity must be provided for each pressure zone. Recommended storage volume is the sum of three components.

- Operational Storage: the volume of water between operational setpoints of pumps and regularly used during daily operations, estimated as 25 percent of MDD
- Fire Storage: the volume of water needed in each zone to meet the largest required fire flow for the duration specified in the Oregon Fire Code
- Emergency Storage: the volume of water needed to supply customers in each zone in the event of an emergency that makes supply to the zone temporarily unavailable. Emergency storage was estimated as 1 x MDD.

Additionally, JWC supply contracts require partner agencies to provide three times the average take from the JWC in regional and partner-controlled storage.

Pump Stations

Pump stations should have adequate firm capacity to meet MDD in the pressure zones they serve. Firm capacity is defined as the station's pumping capacity with the largest pump out of service. In the case that a pump station serves a closed zone, or a zone with no storage or additional sources, the pumps station must provide peak hour demand plus fire flow.

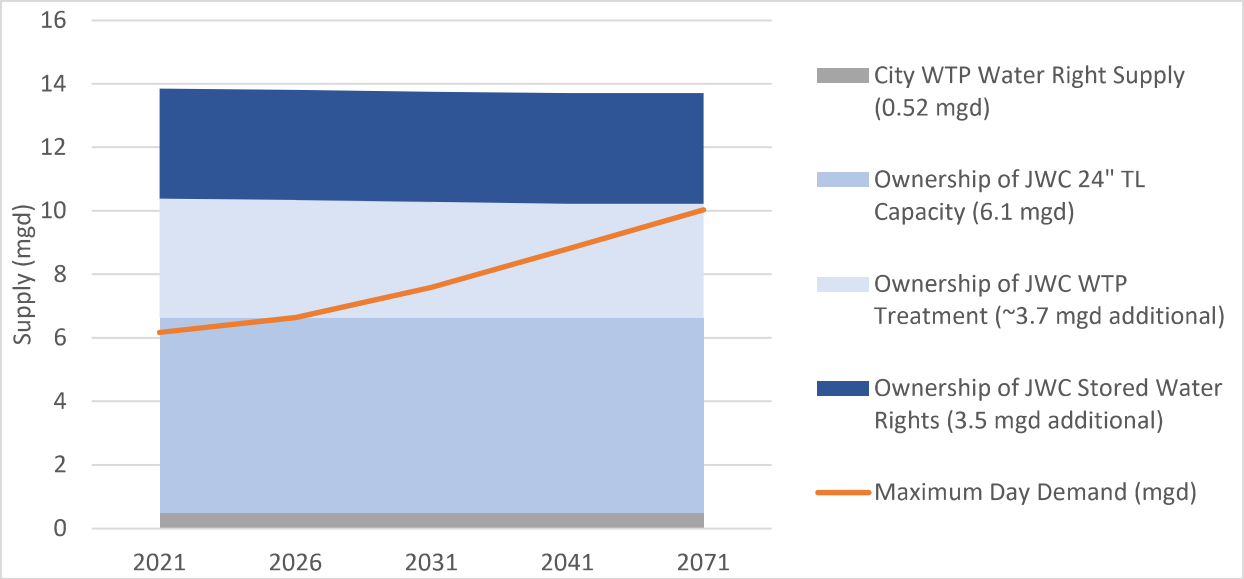
Fire Flow

The distribution system should be capable of supplying recommended fire flows while supplying MDD and maintaining minimum residual pressures of 20 psi everywhere in the system.

Water Supply Analysis

Historically, the City has had sufficient capacity in raw water supply, treatment capacity, and finished water transmission. As the City continues to grow, however, the City's water demands will start approaching the current supply system capacity. In is anticipated the dry season water demands will exceed the City's capacity ownership in the 24" JWC TL in just a few years. To address this shortfall, the City should consider leasing capacity from the City of Hillsboro in this line. A more permanent solution, including addressing seismic deficiencies in this line, should also be considered and is recommended in the SRP. **Figure ES-1-1** highlights the maximum day limitations in the supply system.

Figure ES-1-1 | Supply Limitations during Maximum Demand



Additional action may be required for raw water supply and treatment, depending on future climate conditions, City demand, and long-term supply contract obligations approaching the 50-year planning horizon. Exact limitations on each supply process will depend on how the City decides to address future water supply. Five supply scenarios are summarized at a high level in **Section 4**. To make an informed decision, the City must address a series of knowledge gaps such as documenting requirements for various facility replacements and improvements, understanding lease capabilities from neighboring providers, and estimating costs for each supply alternative and complete a detailed Water Supply Study.

Distribution System Analysis

A hydraulic network model was used to analyze the distribution system, which was evaluated based on the performance criteria described above and projected demands summarized in **Table ES-1-1**. Recommended CIP projects and pressure zone configuration or operational changes were developed based on the deficiencies identified through this analysis.

Fire Flow Analysis

Fire flow scenarios test the distribution system's ability to provide required fire flows at a given location while simultaneously supplying MDD and maintaining a minimum residual service pressure at all services.

Under existing piping conditions, the City has fire flow deficiencies particularly in the industrial area in the east. However, when the Heather Street Control Station is included for fire flow supply, and transmission is upsized between the City WTP, 10th Avenue Control Station, and the Heather

Street Control Station, most fire flow deficiencies are met. Additional limited distribution piping upsizing is included to address remaining deficiencies.

Transmission Limitations

Supply from the JWC through the 10th Avenue Control Station to the City's primary storage at the 5 MG Reservoir is limited by distribution piping. With existing infrastructure, over-pressurization of low elevation customers in the 368 Zone is a risk if the City wants to quickly fill the reservoir from the JWC. Additionally, supply from the new Heather Street connection to the JWC's North Transmission Line (NTL) is similarly limited by distribution piping. As system demands continue to grow, supply transmission through the system will be exacerbated. Therefore, the City should consider upsizing transmission from both the 10th Avenue Control Station and the Heather Street Control Station.

Additionally, transmission upsizing is also recommended from the Watercrest Pump Station to the David Hill Reservoir, assuming the resiliency improvements are made to the Watercrest Pump Station. This will improve supply to future upper zone customers.

Storage Capacity

System storage in all zones will be deficient within the next five years. The City should consider constructing two 5 MG reservoirs at the existing 5 MG Reservoir site and overflow elevation. A phased construction approach is recommended to maintain storage availability in the 368 Zone and match storage with demands as development occurs. Both reservoirs are recommended within the next 10 years, based on existing development assumptions, but site constructability may recommend an alternate phasing schedule.

A 0.5 MG 710 Reservoir is recommended once sufficient development occurs above the 540 Zone. Prior to construction, areas above existing service elevations can be served through future constant pressure pumping from the David Hill Reservoir.

Pump Stations

Pumping capacity is required for service to Zones above the 368 Zone. Pumping to the 540 Zone and David Hill Reservoir is evaluated based on the MDD of the combined upper elevation zones (435, 540, Gales Creek Service Area, and future 710 and 880). Pumping capacity to future closed zones (710 or 880) is evaluated based on the peak hour and fire flow requirement of each zone. Pumping to the 540 Zone must meet the needs of the 540, 435, future 710, and future 880 Zones.

The two existing 540 Pump Stations (David Hill and Watercrest) have sufficient capacity for future supply but need facility improvements to improve reliability and resiliency. Future 710 and 880 pump stations should be constructed as development necessitates. The 710 Pump Station will need to initially provide constant pressure until the 710 Reservoir is constructed. The 880 Pump Station is anticipated to only provide constant pressure.

Additional improvements should be considered for risk mitigation at all pump stations, including adding pump redundancy if it does not exist, regularly exercising pumps that are anticipated to be used as backup supply, and ensuring adequate power with automatic switching and seismic improvements are met.

Water Quality and Conservation

Water Quality Regulations

The City of Forest Grove, along with all public drinking water systems, must follow both state and federal regulations. At the federal level, the Environmental Protection Agency (EPA) establishes water quality standards, monitoring requirements, and enforcement procedures. At the state level, either the EPA or a state agency will implement the EPA rules. As a primacy state, Oregon administers most of the EPA's drinking water rules through the Oregon Health Authority (OHA) Drinking Water Services (DWS). The DWS rules for water quality standards and monitoring are adopted directly from the EPA. The DWS is required to adopt rules at least as stringent as federal rules. To date, the DWS has elected not to implement more stringent water quality or monitoring requirements.

At the Federal level, the Safe Drinking Water Act (SDWA) is the primary drinking water regulation. It was originally enacted in 1974 by Congress to ensure the quality of America's drinking water with a focus on water treatment. The act was reauthorized and updated in 1986 and 1996 to expand protections to source water and improve operator training, system improvement funding, and public education. The SDWA contains the following assignment and programs for the EPA and the states to administer including:

- State revolving loan fund for water system construction
- Public notification reports
- Source water assessment and protection
- Monitoring reductions based on source water protection
- Mandatory certification of operators

These assignments have been implemented by the EPA and/or individual states and are regularly updated. Under the authority of the SDWA, the EPA sets various rules and regulations to maintain safe drinking water.

The City currently meets all existing and proposed water quality regulations that govern the operation and performance of the water system.

Seismic Resilience Evaluation

The City conducted a separate Seismic Resilience Plan (SRP) with InfraTerra, completed in 2020. The SRP fulfills the seismic requirements for Water Master Plans in OAR 333-061-0060(5) (J) and

recommends mitigation measures that can be implemented over the next 50 years to improve seismic resilience of the water system. SRP recommendations are included in the CIP.

System Backbone

Consistent with the Oregon Resilience Plan (ORP) guidelines, the City identified critical facilities and customers like primary care centers that will need uninterrupted or quickly restored water service following the anticipated magnitude 9.0 Cascadia Subduction Zone (CSZ) earthquake. The approach included identification and hardening of key supply, transmission, and distribution facilities (backbone) so that water is available for critical needs such as fire suppression, health and emergency response, and drinking water at key distribution points immediately after the earthquake while damage to the rest of the water system is repaired. This "backbone" was then evaluated to assess risk and develop CIP projects. Figures included in **Appendix H**, *Water System Seismic Resilience Plan* by InfraTerra illustrate the backbone and seismic risks.

Seismic Hazards Assessment

Seismic hazards all have the potential to damage buried water mains and other water facilities. Within the Forest Grove water service area, these hazards were evaluated based on existing magnitude 9.0 CSZ earthquake hazard maps published for the Portland Metro region by the Oregon Department of Geology and Mineral Industries (DOGAMI). These maps were refined using geotechnical exploration data and subsurface boring logs from reservoirs, pump station sites, and various projects constructed near critical water facilities in the City's water service area.

Summary of Recommendations

The seismic resilience recommendations are summarized below.

- Phase I Improvements were identified in the SRP and are intended to meet the ORP goal of 80-90 percent of the backbone operational within 24-hours of a seismic event. These projects are recommended to be completed within 0-5 years.

- Phase II improvements were identified in the SRP and are intended to meet the ORP goal of 80-90 percent of the entire system operational, except for goals related to the non-backbone water distribution system. To meet all the water system goals of the ORP, an additional 25.1 miles of existing ductile iron pipe would have to be replaced with seismically resistant pipe, which is likely cost prohibitive. The recommended phased approach will achieve many, but not all, or the ORP water system goals and when coupled with emergency operations planning, will significantly improve the City's water system seismic resiliency. Projects are generally recommended to be completed within 11-20 years, except for improvements to the JWC Transmission Line which is recommended for 0-5 years and discussed in the supply section and a few long term projects to be completed in 20+ years.

- Additional recommended actions were identified in the SRP to mitigate seismic risk. See **Section 6.6.3** for additional description. These projects are generally either smaller projects or actions identified for the City to complete to aid in post disaster operations and planning. Projects are recommended to be completed within 0-5 years.

Recommended Capital Improvement Program (CIP)

A summary of all recommended improvement projects and estimated project costs is presented in **Table ES-1-2**. **Figure 7-1** included in **Section 7** illustrates these improvements. This CIP table provides for project sequencing by showing prioritized projects for the 5-year, 6 to 10-year, 11 to 20-year, and beyond 20-year timeframes defined as follows.

- 5-year timeframe - recommended completion through 2027
- 6 to 10-year timeframe - recommended completion between 2028 and 2032
- 11 to 20-year timeframe - recommended completion between 2033 and 2042
- 20+ year timeframe – recommended completion beyond 2042

Estimated project costs presented in the CIP are intended to provide guidance in system master planning and long-range project scheduling and implementation. Final project costs will vary depending on actual labor and material costs, market conditions for construction, regulatory factors, final project scope, project schedule, and other factors.

The City's proposed CIP includes significant investment, particularly in supply, storage, and seismic improvements. This new capacity will serve growth while also providing more resilient water facilities that benefit all customers. An evaluation of water rates and system development charges (SDCs) in support of the water system CIP will be completed as follow-on work to this WSMP.

Table ES-1-2 | CIP Cost Summary

Project Type	0-5 Years	6-10 Years	11-20 Years	20+ Years	20-Year Total
Supply	$2,595,000	$-	$7,640,000	$44,560,000	$10,235,000
Storage Reservoirs	$11,300,000	$11,300,000	$1,000,000	$-	$23,600,000
Pump Stations	$2,100,000	$-	$850,000	$-	$2,950,000
Piping Improvements	$7,840,000	$5,040,000	$8,210,000	$-	$21,090,000
Seismic Improvements	$22,047,500	$50,000	$4,100,000	$40,610,000	$26,197,500
Planning	$50,000	$300,000	$300,000	$-	$650,000
Total	**$45,932,500**	**$16,690,000**	**$22,100,000**	**$85,170,000**	**$84,722,500**

Note:

1. 20 Year Total does not include projects after 20 years (approximately an additional $85M).



Section **1**

Section 1

Introduction and Existing Water System

1.1 Purpose

The purpose of this Water System Master Plan (WSMP) is to perform an analysis of the City of Forest Grove's (City's) water system and:

- Document water system upgrades, changes, and growth since the 2010 *Water Master Plan*
- Estimate future water requirements including potential water system expansion areas
- Document the City's recent water system seismic resilience evaluation
- Identify deficiencies and recommend water facility improvements that correct deficiencies and provide for growth
- Provide a recommended, prioritized Capital Improvement Program (CIP) for the water system
- Comply with water system master planning requirements for Public Water Systems established under Oregon Administrative Rules (OAR)

This report is divided into seven sections to address the goals described above. Section 1, Section 2, and Section 3 summarize the existing system and water demands, estimate future water demands, and list the performance criteria used to analyze the system. Section 4 and Section 5 build off the prior sections to identify system deficiencies, vulnerabilities, and development improvements projects for the supply and distribution systems. Section 6 summarized the Seismic Resilience Plan (SRP) developed by InfraTerra. Section 7 compiles the proposed projects into a CIP prioritized in 5-year increments. The planning and analysis efforts presented in this WSMP are intended to provide the City with the information needed to inform long-term water supply and distribution infrastructure decisions.

This plan complies with water system master planning requirements established under Oregon Administrative Rules for Public Water Systems, Chapter 333, Division 61 (OAR 333-061-0060(5)).

1.2 Service Area

The City is located west of Portland, in rural Washington County adjacent to the City of Cornelius and provides finished water to approximately 26,000 residents through approximately 6,800 residential, commercial, industrial, and municipal service connections. In addition to residential development and a small downtown business district, the City's customers include Pacific University, technology industry manufacturers, and food processing companies. The current service area includes all areas within the existing city limits and historic customers located outside the Urban Growth Boundary (UGB) along Gales Creek, Stringtown Road, Oppenlander Lane, and Martin Road. The study area of this planning effort is the current UGB, including the David Hill and Purdin Road areas as described in the City's *2017 Westside Planning Program*. The City's service area is illustrated on **Figure 1-1**, located at the end of this section.

1.3 Supply

The City owns and operates a water treatment plant (WTP) which treats raw water from the Clear Creek watershed, a tributary of Gales Creek located northwest of the City. During seasonally high stream flows, the City has sufficient source water to meet existing demands. Additional supply is available from the Joint Water Commission (JWC) which treats Tualatin River raw water and supplies finished water to the City. The JWC is a water authority formed in 1976 through an intergovernmental agreement (IGA) between the Cities of Hillsboro and Forest Grove. Currently, the JWC also includes the City of Beaverton and the Tualatin Valley Water District (TVWD). Typically, the City draws from JWC supply from July through September. Supply from both the Clear Creek watershed and the Tualatin River is limited in the dry season due to in-stream flow requirements. During the dry season, the City must reduce raw water take from the watershed due to water right restrictions. The JWC, however, offsets lower in-stream flows with stored water released from local impoundments, Barney Reservoir and Hagg Lake (Scoggins Reservoir). The JWC then treats and supplies this finished water through its usual system. Key aspects of the supply system are illustrated in **Figure 1-2**, located at the end of this section.

1.3.1 Water Rights

The City holds live water rights on Roaring Creek, Clear Creek, and Gales Creek as well as the Tualatin River. The City's Tualatin River rights are used to supply raw water to the JWC WTP. The City also holds stored water rights in Barney Reservoir and Hagg Lake. Water rights are discussed in more detail in **Section 4**.

1.3.2 City Source Transmission

The City's raw water supply comes from five intake facilities within 4,225 City-owned acres of the Clear Creek watershed, a sub-watershed of the Gales Creek watershed. Intake facilities are located along Clear Creek, Deep Creek, Smith Creek, Thomas Creek, and Roaring Creek. The raw water is piped approximately 7.8 miles southeast to the WTP located on Watercrest Road, through 16-inch

concrete cylindrical pipe (CCP) alongside Gales Creek and Gales Creek Road. Watershed piping from the intake facilities to the 16-inch CCP Raw Water Transmission Main (RWTM) includes cast iron, cast iron tyton, and other pipe material. Typically, the RWTM flows by gravity with a maximum capacity of approximately 1,875 gallons per minute (gpm) (2.7 million gallons per day (mgd)). During high demand periods and when water is available in stream, the Raw Water Pump Station (PS), located along Gales Creek Road next to Forest Glen Park, can increase flows up to 2,600 gpm (3.7 mgd).

1.3.3 City WTP

The City's treatment plant is of conventional design with coagulation, flocculation, sedimentation, and rapid sand filtration. The plant has a maximum production capacity of approximately 3.7 mgd. According to City WTP staff, the minimum flow for efficient operation of feed pumps is approximately 475 gpm (0.68 mgd). The City adds alum as its primary coagulant and uses horizontal mounted, paddle wheel flocculators. Water is settled in a single sedimentation basin, then a low-head pump lifts the settled water to the gravity rapid sand filters. Prior to storage, two chlorine feed points can be operated either individually or simultaneously to meet disinfection requirements. Finished water is stored onsite at the 5.0 million gallon (MG) reservoir, which provides service pressure for the City's 368 Zone.

The WTP is primarily limited by the loading rate of its rapid sand filters, which operate at 5 gpm per square foot. WTP operation can also be affected by a storm that causes high turbidity in the Clear Creek watershed where the City's intakes are located. The WTP filters do not function efficiently with high volumes of suspended particles due to more frequent filter backwashing. This also results in higher volumes of waste solids that need to be removed from the site.

1.3.4 JWC Supply

The JWC supplies drinking water to communities in Washington County, including the Cities of Forest Grove, Hillsboro, Beaverton, TVWD, and other wholesale customers.

1.3.4.1 Source Intake and WTP

The JWC intake facility and treatment plant is located on the Upper Tualatin River off Fern Hill Road, in unincorporated Washington County and approximately 1.5 miles south of Forest Grove City limits. The plant is jointly owned by the JWC members but maintained and operated by the City of Hillsboro. The treatment plant is of conventional design with coagulation, flocculation, sedimentation, and rapid sand filtration processes. Treatment capacity is limited to 85 mgd, of which the City owns 10 mgd. A recent 10 mgd JWC WTP expansion was designed to meet current seismic standards, however Forest Grove did not participate in the expansion.

1.3.4.2 Finished Water Storage and Transmission

Finished water is pumped one-third of a mile east to the JWC's two 20 MG buried concrete reservoirs at Fern Hill (40 MG total storage capacity). Forest Grove is supplied by a 24-inch gravity JWC Transmission Line (TL) from either the Fern Hill reservoirs or directly from the JWC WTP. (This line is also sometimes referred to as the Forest Grove/Hillsboro Transmission Line.) This 24-inch CCP, approximately 8,200 linear feet (LF) as identified by geographic information system (GIS) data provided by the City of Hillsboro, is jointly owned by the Cities of Forest Grove and Hillsboro. JWC water enters the Forest Grove system at the 10th Avenue Control Station.

A 72-inch gravity transmission main from the Fern Hill reservoirs, the JWC North Transmission Line (NTL), runs through the east side of the City to supply JWC partners Hillsboro and TVWD. The City is not currently connected to the 72-inch JWC NTL.

1.3.4.3 10th Avenue Control Station

The 10th Avenue Control Station is Forest Grove's only connection to the City's JWC supply. At the station the JWC Fern Hill hydraulic grade line (HGL) is reduced to match the City's 368 Zone and flow into the Forest Grove system is metered for both the City's and JWC's use. The station can be operated on either pressure or flow control. Currently it is operated on pressure control following a 2020 replacement of the station's control valves. Water is also fluoridated at the control station.

As described previously, the City typically draws on JWC supply from July through September during low stream flows in the Clear Creek Watershed which supplies raw water to the City WTP. The City informs the JWC when they will begin withdrawing water at the 10th Avenue Control Station and notifies JWC operators of any significant expected changes in demand.

1.3.5 Emergency Interties

The City maintains a single 6-inch emergency intertie with the City of Cornelius, located on Heather Street at the city limits. This intertie has not been exercised in the past 10 years and capacity estimates for supply in either direction are unavailable. It is expected that supply will be limited and dependent on operating conditions of the two systems when an emergency occurs.

The City of Cornelius is planning a second intertie with the Forest Grove water system in N Adair Street, east of its intersection with Yew Street. According to Cornelius' *2017 Water Master Plan*, the project will connect an existing 12-inch line in N Adair Street in Cornelius to an existing 10-inch line in Adair Street in Forest Grove.

An existing blind flange along the JWC's 72-inch JWC NTL will serve as a future emergency intertie connection point at Mountain View Lane and Heather Street. In 2021 the City began designing the Heather Street Control Station, an emergency intertie with the 72-inch JWC NTL at this location.

1.4 Pressure Zones

The City's existing distribution system is divided into four service levels, or pressure zones. The pressure zones have previous been identified as the Lower, Intermediate, and Upper Pressure zones, and the Gales Creek Service Area (GCSA). Pressure zones are defined by ground topography based on the Forest Grove Vertical Datum and are designed to provide acceptable pressures to all customers in each zone. Zones are designated by HGLs which are set by overflow elevations of water storage facilities or by outlet settings of pressure reducing facilities serving the zone. Pressure zone boundaries are further refined by street layout and specific development projects. Because future growth is anticipated above the Upper Zone, the zones have been renamed according to their HGLs for the purposes of this report and future development: 368, 435, 540, and Gales Creek Service Area. The HGL varies considerably, from about 420 to 450 feet, among the six pressure reducing valves (PRVs) serving the Intermediate Zone. The approximate median of 435 feet lends the zone its new name.

Table 1-1 presents a summary of existing pressure zones. Pressure zones are illustrated on Plate 1 in **Appendix A** and the hydraulic schematic in **Figure 1-3** at the end of this section.

Table 1-1 | Pressure Zones

Zone	Previous Name of Zone[1]	HGL (ft)	Ground Elevations Served (ft)	No. Connections
368[2]	Lower	368	< 270	6,142
435[3]	Intermediate	381-446	270 – 330	188
540[4]	Upper	540	330 – 440	418
GCSA	Gales Creek	400	190 – 320	64

Notes:

1. The pressure zones were renamed according to their HGLs because future growth is anticipated in the David Hill UGB and David Hill Urban Reserve Area (DHURA) above the elevation currently served by the Upper Zone.
2. The Lower Pressure Zone was renamed as the 368 Zone, designated by the reservoir overflow elevation of 368 feet at the 5 MG Reservoir.
3. The Intermediate Pressure Zone was renamed as the 435 Zone, based on an average of the pressure settings of the six PRVs that serve the zone.
4. The Upper Pressure Zone was renamed as the 540 Zone, designated by the reservoir overflow elevation of 540 feet at the David Hill Reservoir.
5. Elevations are based on the Forest Grove Vertical Datum.

1.4.1 368 Pressure Zone

Most of the City is within the 368 Zone. The 368 Zone is supplied by the City's 5 MG Reservoir at the City WTP site and from the JWC at the 10th Avenue Control Station. The 5 MG Reservoir overflow elevation is 368.75, which sets the maximum HGL for the 368 Zone. There is one PRV station, the Forest Gale PRV, installed between the 435 and 368 Zones which only operates during fire flow conditions. The 368 Zone includes nearly all the City's industrial and commercial customers, along with Pacific University and most of the City's residential neighborhoods.

1.4.2 435 and 540 Pressure Zones

The existing 435 and 540 Zones primarily serve residential customers in the northwest reaches of the City. The 540 Zone is supplied by the David Hill Reservoir, which sets the zone's HGL at a maximum of 540 feet. The reservoir is filled through the distribution system by the David Hill and Watercrest Road Pump Stations. The 435 Zone is served by six PRVs supplying water from the 540 Zone's distribution system. These PRVs are summarized in Table 1-2 and illustrated on Plate 1 in Appendix A.

1.4.3 Gales Creek Service Area

The GCSA serves customers northwest of the City, outside the UGB, along Gales Creek Road, Stringtown Road, and Oppenlander Lane. Until 1994, these customers were served directly off the 16-inch RWTM supplying the City's WTP. Water customers can no longer be served off the raw water line due to the surface water treatment regulations of OAR Chapter 333. Therefore, the GCSA has been disconnected from the raw water main. Currently, a distribution system of primarily 4 to 6-inch Class 160 polyvinyl chloride (PVC) pipes supplies customers from the 540 Pressure Zone through a PRV station located in a City utility access road near Gales Creek Road and NW Creekwood Place.

Portions of the GCSA distribution piping are unmapped and are believed to cross private property, including active farmland, without easements. The Service Area is operated at relatively high pressure, approximately 90 pounds per square inch (psi), to overcome head loss through the small diameter distribution mains and supply adequate service pressure to the last customers on the line who are also at the highest elevations. City distribution system operators perform a monthly water audit of the Service Area by comparing metered flows through the Gales Creek PRV station with GCSA customers' metered consumption. City staff have been able to identify some leaks and significantly reduce water loss; based on a water audit completed by City staff for this service area, water loss is currently estimated at approximately 21,500 gallons per day (645,600 gallons per month).

Table 1-2 | PRV Station Summary

Station Location	Higher Zone	Lower Zone	Pressure Setting (psi)	HGL (feet)
Forest Gale Drive & Gales Creek Road	435	368	63	380
3222 Valley Crest Way	540	435	52.5	446
Lavina & Forest Gale Drives	540	435	51	413
3214 Forest Gale Drive	540	435	49.5	419
3130 Forest Gale Drive	540	435	58	436
3145 Fleming Place	540	435	51	433
3151 Vista Drive	540	435	39	381
Gales Creek Road & NW Creekwood Place	540	GCSA	92.5	446

1.5 Storage Reservoirs

1.5.1 City Storage

The City owns two finished-water storage facilities with a combined storage capacity of 6.0 MG, the 5 MG Reservoir serving the 368 Zone and the David Hill Reservoir serving the 540 Zone.

1.5.1.1 WTP 5 MG Reservoir

The 5 MG Reservoir at the City's WTP is a buried 304-foot by 152-foot, rectangular hopper-bottom reinforced concrete structure built in 1948. The reservoir is divided into two equal tanks, allowing for continued operation during maintenance operations on half the reservoir. The 5 MG Reservoir typically operates at an HGL of 367 feet, 1.75 feet below the overflow. The reservoir features a 5-foot hopper bottom at its center. This reservoir sets the HGL for the 368 Zone.

1.5.1.2 David Hill Reservoir

Located on David Hill Road, just northwest of the city limits, the 1.0 MG David Hill Reservoir provides storage for the 540 and 435 Pressure Zones. The reservoir is a 96-foot by 76-foot partially buried reinforced concrete structure built in 1985. The reservoir sets the hydraulic grade for the 540 Zone and is typically operated at an HGL of 538 feet, two feet below the overflow.

1.5.2 JWC Storage

The JWC has a combined storage volume of 40 MG in two 20 MG reservoirs, known as the Fern Hill Reservoirs. Both reservoirs are located off Spring Hill Road, south of Forest Grove, just a third of a mile east of the JWC WTP. The first reservoir was built in 1978 and rehabilitated in 2006. The second reservoir was built in 2006.

The City owns 5.3 MG of the 40 MG storage volume; however, 40 percent of the combined storage is allocated to the JWC WTP for operation purposes (JWC Operations Manual, Section 6). The remaining 60 percent is distributed to JWC members by ownership This leaves approximately 3.2 MG of Fern Hill storage available for City use. Table 1-3 provides details of the four reservoirs serving the City.

Table 1-3 | Reservoir Summary

Name	Service Area	Capacity (MG)	Overflow Elevation (ft)	Operating Elevation (ft)	Floor Elevation (ft)	Year built	Tank Type
JWC Fern Hill 1 & 2	368 Zone	40 MG Total/ 3.2 MG Available[1]	520	515	492	1982/ 2006	Partially-buried prestressed concrete
WTP (5 MG)	368 Zone	5.0	368.75	367	348	1948	Buried reinforced concrete
David Hill	540 and 435 Zones	1.0	540	538	520	1985	Partially-buried reinforced concrete

Note:
1. 40 percent of total JWC storage (40 MG) dedicated to JWC WTP operations. Remaining 24 MG divided by ownership results in 3.2 MG storage available for City use.

1.6 Pump Stations

The City's water system includes a raw water booster pump station used to increase transmission capacity from the Clear Creek watershed intakes to the City's WTP and two finished water distribution system pump stations used to boost finished water from the 368 Zone to the 540 Zone. Pump stations are summarized in Table 1-4.

1.6.1 Raw Water Pumping

The Raw Water Pump Station is located along Gales Creek Road. Under normal conditions, the raw water system operates under gravity, which is limited to approximately 2.7 MGD. During high demand periods, the Raw Water Pump Station increases flows up to 3.7 MGD. This station, constructed in 1979, consists of a single, split-case pump housed in an underground vault. The pump is exercised yearly.

1.6.2 Distribution System Pumping

The City's two finished water distribution pump stations lift finished water from the 368 Pressure Zone to the 540 Zone through 10 and 12-inch ductile iron piping.

1.6.2.1 David Hill Pump Station

Built in 1985, the David Hill Pump Station is located on David Hill Road, about one-quarter mile west of Thatcher Road. A brick pump station building houses two identical 25 horsepower (hp), 400 gpm vertical turbine pumps. The pumps run lead-lag based on the level of the David Hill

Reservoir. The pumps are exercised monthly during the low demand winter season and are otherwise only needed during peak demand.

1.6.2.2 Watercrest Pump Station

The Watercrest Pump Station consists of one 280 gpm end-suction centrifugal pump, with a provision for a second pump, housed in a partially buried concrete structure. It is located on Watercrest Road, adjacent to the WTP. As of 2006, the Watercrest Pump Station is used as the primary pump station feeding the David Hill Reservoir and 540 Pressure Zone. The pump was upgraded as part of WTP modifications and the David Hill Pump Station is now used as the back-up.

Table 1-4 | Pump Station Summary

Pump Station	From Zone	To Zone	No. of Pumps	Station Capacity (gpm)	Firm Capacity (gpm)	Pump Type
Raw Water PS	Intakes	368	1	2,600	0	Split-case
David Hill PS (Finished Water)	368	540	2	800	400	Vertical turbine
Watercrest Road PS (finished Water)	368	540	1	280	0	End-suction centrifugal

Note:

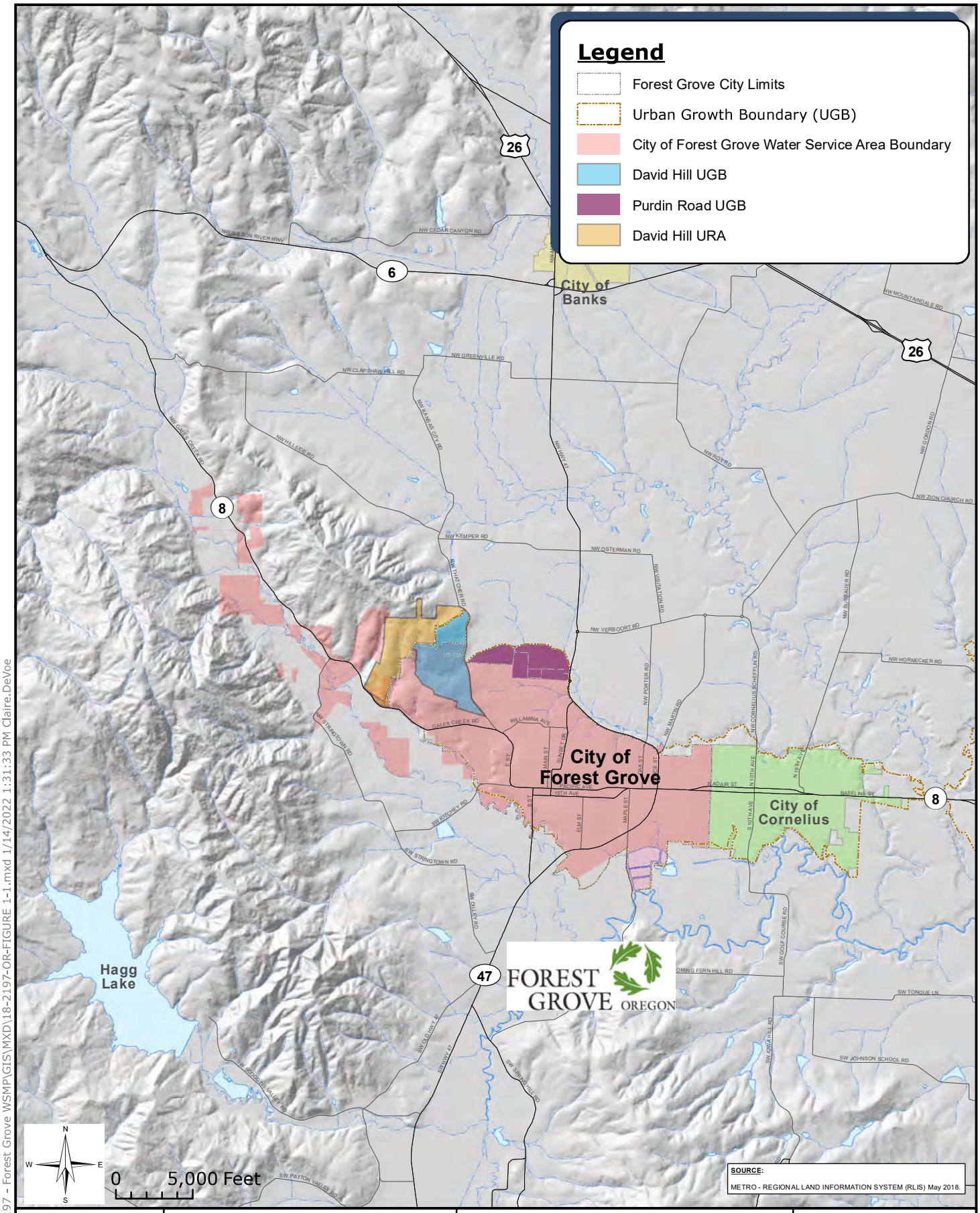
1. Firm capacity is the station capacity with the largest pump out of service. Firm capacity of the Raw Water PS and the Watercrest PS is 0 gpm as there is only one pump at each facility.

1.7 Distribution System

The City's distribution system contains approximately 91 miles of distribution main piping, most of which is 8-inch diameter, ductile iron pipe. Pipes are composed of various materials, including cast iron, ductile iron, asbestos cement (AC), and PVC, in sizes up to 24 inches in diameter. Cast iron mains were constructed mostly in the 1950s and 1960s while most newer distribution piping is ductile iron. A total of 692 fire hydrants are located throughout the system. **Table 1-5** presents an inventory of piping by diameter and material.

Table 1-5 | Length (miles) of Transmission and Distribution Piping by Diameter and Material

Diameter (inch)	Ductile Iron	Cast Iron	Other	Total (miles)
≤ 4	0.88	1.13	9.66	11.68
6	11.01	15.75	1.46	28.22
8	25.19	9.52	0.26	34.96
10	4.90	3.58	0.13	8.60
12	4.02	1.66	-	5.68
16	0.08	0.38	0.01	0.47
20	-	1.28	-	1.28
24	0.56	-	-	0.56
Total (miles)	46.64	33.30	11.52	91.45



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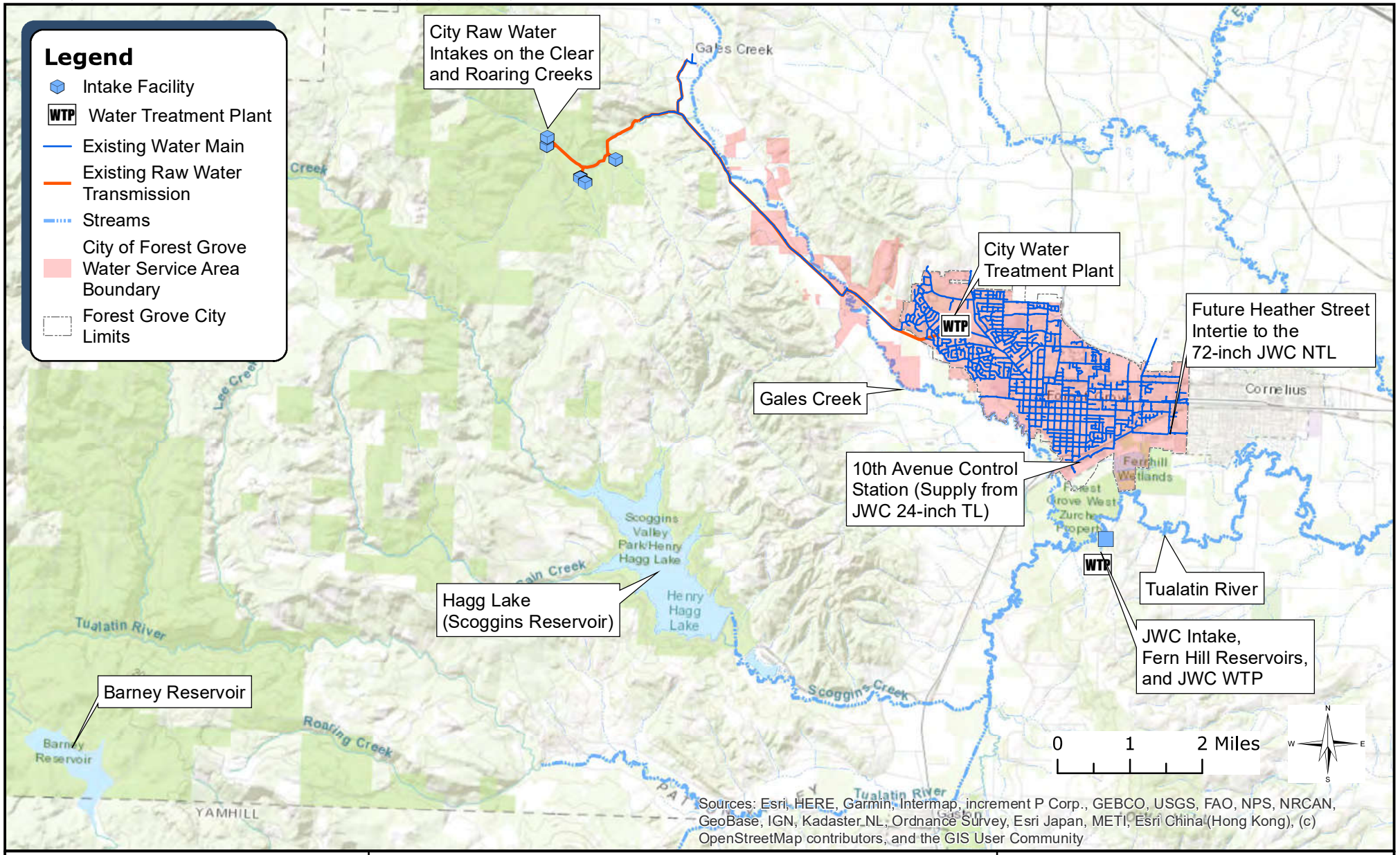
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City of Forest Grove Water System Master Plan

Figure 1-1 Water Service Area Map

FOREST GROVE OREGON

January 2022 18-2197

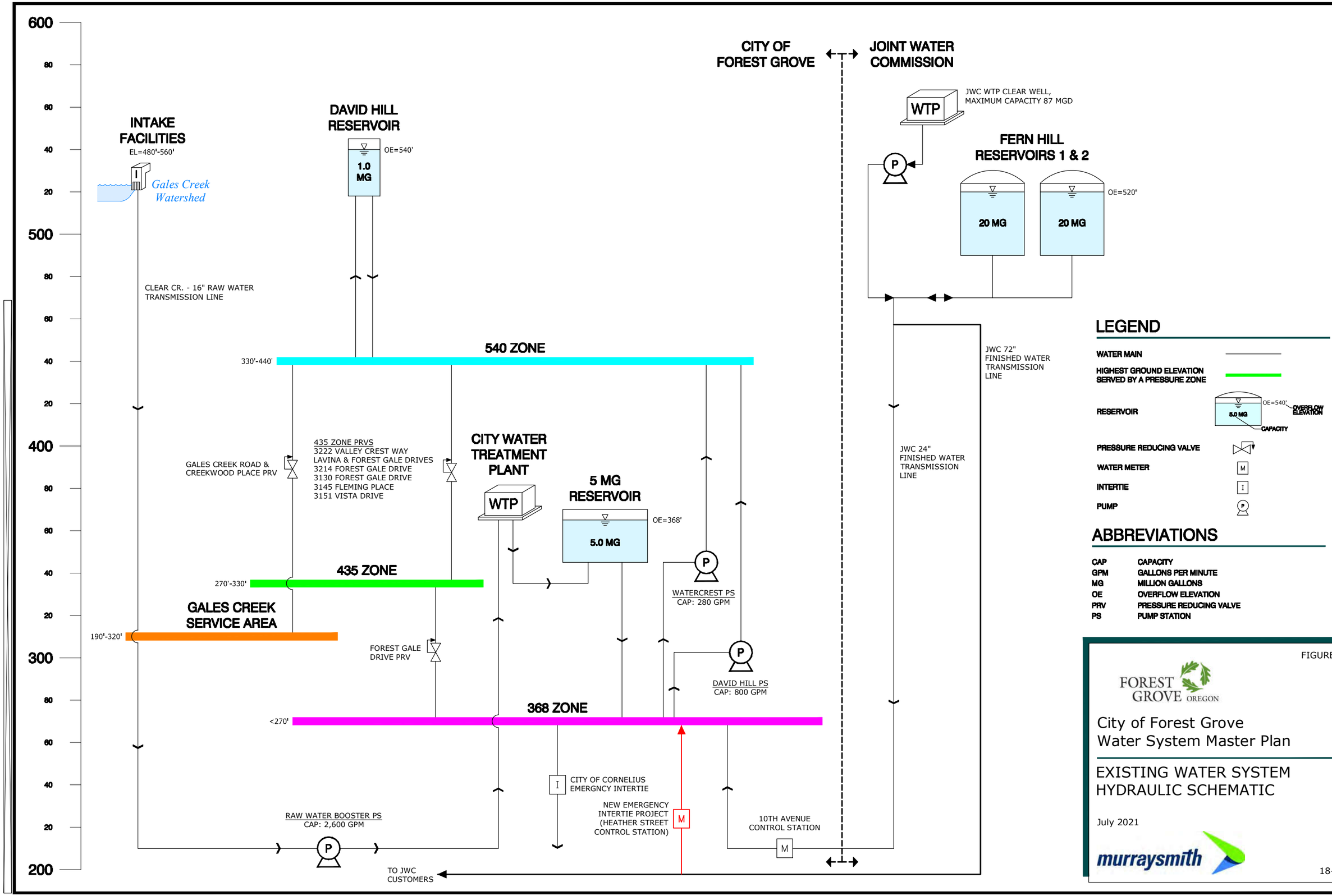


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FOREST GROVE OREGON

City of Forest Grove
Water System Master Plan

Figure 1-2
Source of Supply



LEGEND

- WATER MAIN
- HIGHEST GROUND ELEVATION SERVED BY A PRESSURE ZONE
- RESERVOIR (5.0 MG, OE=540', OVERFLOW ELEVATION, CAPACITY)
- PRESSURE REDUCING VALVE
- WATER METER (M)
- INTERTIE (I)
- PUMP (P)

ABBREVIATIONS

CAP	CAPACITY
GPM	GALLONS PER MINUTE
MG	MILLION GALLONS
OE	OVERFLOW ELEVATION
PRV	PRESSURE REDUCING VALVE
PS	PUMP STATION

FIGURE 1-2

FOREST GROVE OREGON

City of Forest Grove
Water System Master Plan

EXISTING WATER SYSTEM HYDRAULIC SCHEMATIC

July 2021

murraysmith

Section 2

Section 2

Water Requirements

This section presents existing and projected future water demands for the City's water service area. Water demand forecasts presented in this section are used with performance criteria presented in Section 3 to evaluate the existing water system's capacity to serve current customers and future growth. Demand forecasts are developed from historical water consumption and production records, regional planning data, current land use designations, and previous City water planning efforts.

2.1 Water Service Area

2.1.1 Existing Service Area

As illustrated in Figure 1-1, the City's existing water service area encompasses all areas within the existing city limits and customers located outside the UGB along Gales Creek Road, Stringtown Road, and Oppenlander Lane (referred to as the GCSA), and along Martin Road.

2.1.2 Future Service Area

The future service area and the study area for this WSMP includes all areas within the city limits, the GCSA, and the UGB, including the David Hill and Purdin Road areas as described in the City's *2017 Westside Planning Program*. The GCSA and services along Martin Road are assumed to remain constant without adding new customers.

The David Hill Area has been included in the City's UGB since the 1980s. The Purdin Road Area was added to the UGB in 2014. The majority of these two areas is anticipated to be developed within 20 years.

Water demand projections presented in this section also include consideration of the existing David Hill Urban Reserve Area (DHURA) within a 50-year planning horizon. It is assumed future development in the DHURA would begin sometime after 2041.

2.2 Planning Period

The planning period for this WSMP is 20 years, through the year 2041, consistent with OAR requirements for WSMPs (OAR 333-061). Water demand projections presented in this section also include a 50-year projected water demand for long-range water supply planning.

2.3 Water Demand Description

Water demand refers to all finished water required by the system including residential, commercial, industrial, and institutional uses. Water demands are described using three water use metrics: average daily demand (ADD), max day demand (MDD), and peak hour demand (PHD). Each of these metrics is stated in gallons per unit time such as mgd and in gallons per capita per day (gpcd). Peaking factors are used to convert between ADD, MDD, and PHD.

- ADD is the total annual water volume used system-wide divided by 365 days per year.
- MDD is the largest 24-hour water volume for a given year. In western Oregon, MDD typically occurs each year between July 1st and September 30th.
- PHD is estimated as the largest hour of demand on the peak water use day.

2.3.1 Water Production vs. Consumption

Water demand can be calculated using either water consumption or water production data. Water consumption data is taken from the City's customer billing records and includes all revenue metered uses. This data can be analyzed by geographical location and customer type which is useful for quantifying typical water use for different land uses. However, consumption data does not capture any water loss or unmetered uses and is only recorded in monthly totals making it less useful in determining system-wide peak demands.

Water production is measured as the water supplied to the distribution system. The City's total daily water production is the sum of the recorded finished water flow measured at the City's WTP and at the 10th Avenue Control Station (JWC Supply). Total water production is used for analyzing seasonal water demand trends, supply, and storage capacity. Water production includes billed consumption (customer billing records), unmetered uses such as hydrant flushing, and water loss through minor leaks and unregulated use.

The difference between water production and consumption including unmetered uses is known as water loss and is typically presented in a percent. Oregon rules set a maximum water loss allowance for systems such as Forest Grove of 10%. Systems that do not meet this maximum are required to implement programs to reduce water loss.

2.4 Historical Water Demand

System-wide historical water demand is presented in Table 2-1.Typically, 5 years of historical data would be used to evaluate system demands. However, due to lack of valid metering, only the prior 3 years were used. This is discussed more in Section 2.4.1. It is also worth noting that the Covid-19 pandemic affected 2020 data. However, with only one year of data, it is unclear exactly to what extent water use patterns changed. Even with these unique circumstances, the City's water use

has remained constant over the past three years and so 2018-2020 data was assumed sufficient to develop a baseline for this plan.

Water consumption is calculated from the City's monthly billing data. Unmetered water use was provided by the City and includes permitted hydrant use, flushing, and backwash at the City's WTP. Water production is calculated daily as finished water supplied from the City's WTP plus the water supplied from the JWC through the 10th Avenue Control Station.

The City's average water loss for 2018-2020 was 14%. The City currently has a water loss reduction framework in place as recommended and discussed in the JWC Water Management and Conservation Plan (WMCP, 2021). The reduction program includes annual water audits, replacement of master meters, a regular meter testing and maintenance program, a water rate structure to encourage conservation, a public education program, potential expansion of the home energy audit program to include water use, and the continuation of a rebate program for high efficiency machines. Benchmarks at 2 and 5 years are also in place to ensure reduction of water loss to 10% or less. Future demands are estimated based on consumption factors, then scaled up to include water loss and unmetered water use. In 2021, water loss is estimated as 14% and unmetered use at 2% of the total demands, while in future years, water loss is estimated as 10% water loss and unmetered use at 2% of the total demands.

Table 2-1 | Historical Water Demand

Year	Production Total (MG)[1]	Consumption Total (MG)	Unmetered Water Use (MG)[2]	Water Loss (MG)	Water Loss (%)
2018	1181	990	20	172	15%
2019	1141	978	21	142	12%
2020	1153	957	19	177	15%
Average	**1158**	**975**	**20**	**164**	**14%**

Note:

1. Production data calculated as the sum of Forest Grove WTP production and JWC supply through 10th Ave. As discussed in Section 2.4.1, the 10th Ave meter reads low, therefore corrections were used to develop JWC supply assumptions.
2. Unmetered water use includes permitted hydrant use, flushing, and backwash volumes as calculated by the City. This accounts for approximately 2% of the total production.

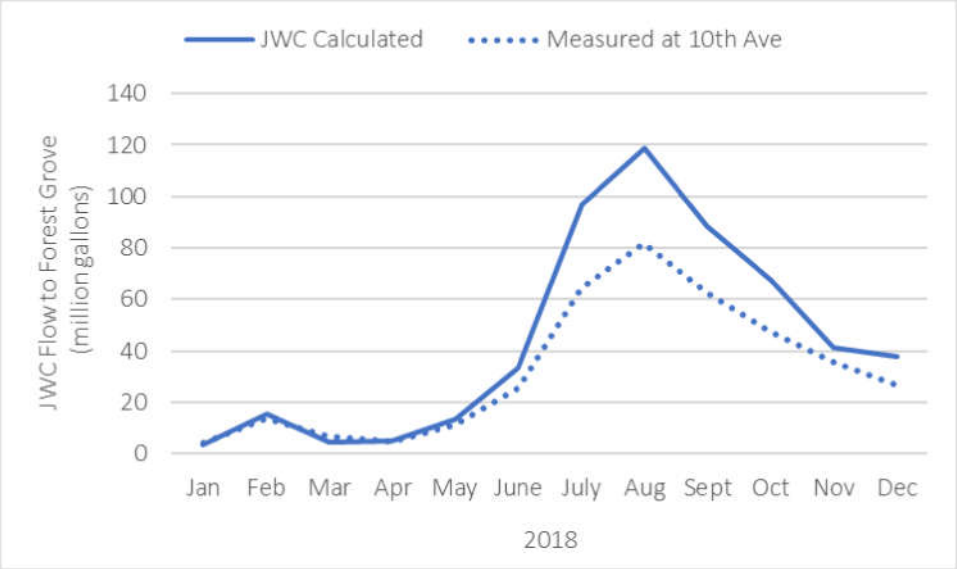
2.4.1 JWC Meter Corrections

In spring 2019, the City discovered that the 10th Avenue Control Station flow meter had not been accurately measuring flows into the distribution system from the JWC. Installation of a JWC flow meter in late 2017 that measures finished water in the 24-inch JWC TL allowed comparison of JWC flow to Forest Grove with metered flow at the 10th Avenue Control Station. Findings of the JWC's metered flow analysis are documented in the May 6, 2019 memo "Uncounted flows along 24-inch JWC TL between JWC Plant and delivery points at the City of Hillsboro Dilley and Forest Grove pressure reducing valve (PRV) facilities" (included as **Appendix B**).

The metered flow differences are generally at flow rates greater than approximately 500 gpm (approximately 22 million gallons/month assuming average flow) and are thus more pronounced

during the peak summer season as shown in **Figure 2-1**. These 10th Avenue Control Station meter inaccuracies impact both historical average and MDD metrics. It is unknown how long the 10th Avenue meter may have been registering inaccurate flow readings because JWC's 24-inch flow meter data is only available starting in fall 2017. For the purposes of this WSMP, demand metrics that reference JWC supply use the corrected flows developed using a combination of the 10th Ave meter for flows less than 500 gpm, the difference between the JWC 24" meter and the Hillsboro Dilley meter when available, and an escalated 10th Ave meter when no better information is available.

Figure 2-1 | 2018 Monthly JWC Metered Flow Differences



Note: November and December 2018 Hillsboro Dilley meter flows were not available due to meter updating. JWC calculated flows for these months are estimated based on 2017 Dilley meter data scaled based on the ratio of 2017 to 2018 peak flows.

2.4.2 Historical Demand and Peaking Factors

Average day and maximum day demand (ADD and MDD) are calculated based on production data. A system wide peaking factor to convert from ADD to MDD is calculated, however more specific peaking factors based on customer classification are used for demand projections in this analysis. Data was not available to calculate a PHD:MDD peaking factor. Based on recent experience with other regional water providers, a peak hour factor of 2 is assumed for future demand projections. An MDD to maximum month peaking factor was also calculated from production data. This conversion factor is 1.19 and is used for calculating MDD from consumption based data, where only monthly demands are available.

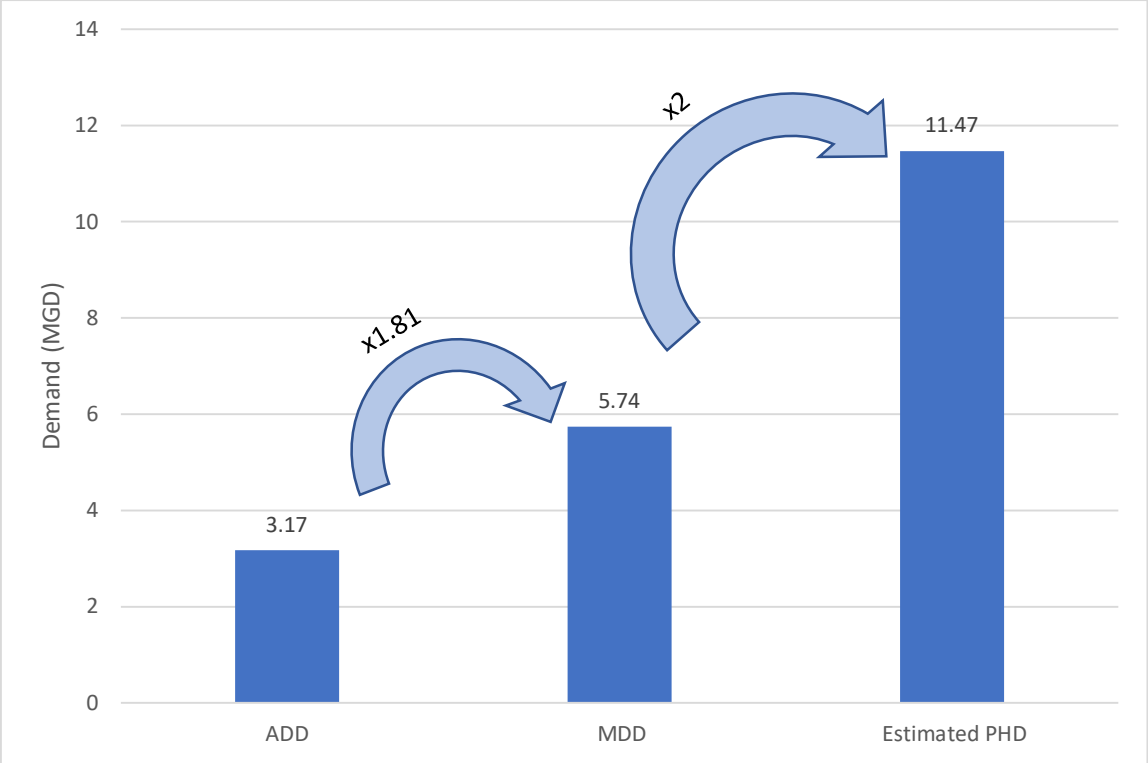
Table 2-2 | Historical ADD, MDD, and PHD

Year	ADD, based on Production (MGD)	MDD, based on Production (MGD)	Estimated PHD (MGD)	MDD:ADD Peaking Factor
2018	3.24	5.83	11.66	1.80
2019	3.13	5.62	11.23	1.80
2020	3.15	5.76	11.53	1.83
Average	**3.17**	**5.74**	**11.47**	**1.81**

Note:

1. A peaking factor of 2 was assumed for PHD:MDD conversion. No hourly data was available to calculate this from City data and so a factor typical of similar systems was used.

Figure 2-2 | Average Production (2018-2020)



2.4.3 Water Demand by Pressure Zone

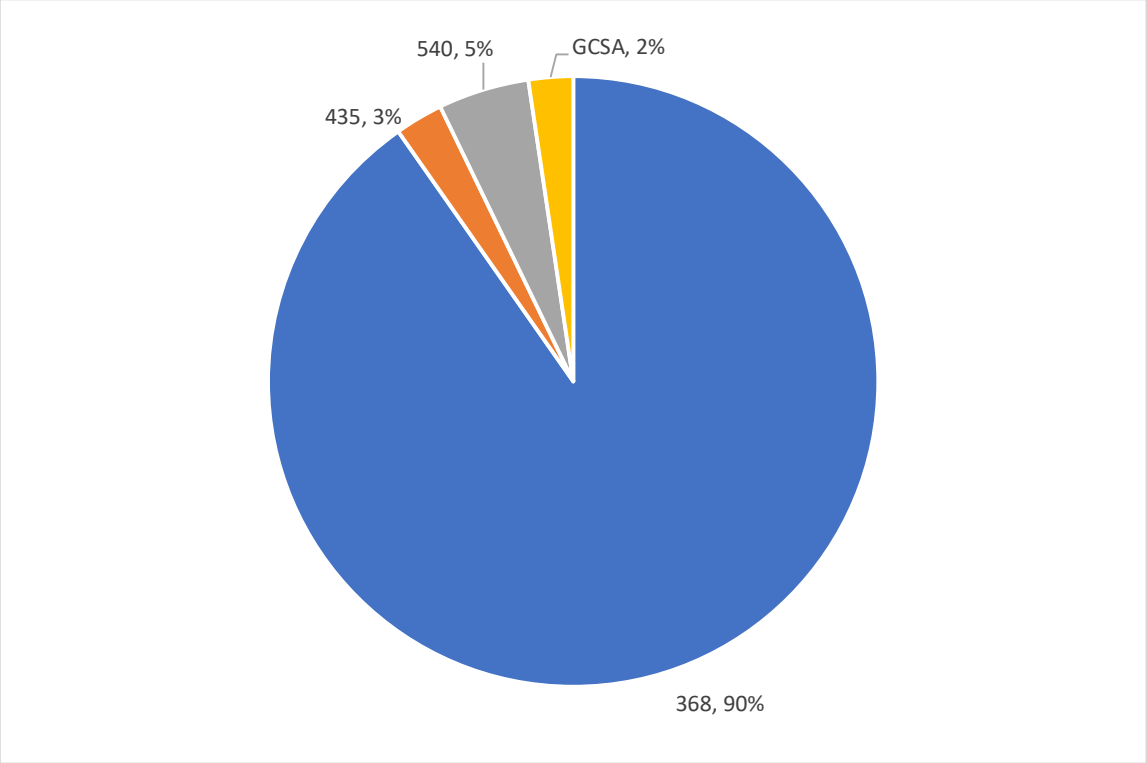
Water billing records provided by the City were used to document current average daily water consumption by pressure zone, customer type, and to correlate non-residential water demand to land use for future demand projections.

Table 2-3 and **Figure 2-3** present ADD by zone, based on the geolocated billing records. Almost all the water use in the system occurs in the main, 368 Zone.

Table 2-3 | Historical ADD by Pressure Zone, Average 2018-2020

Zone	ADD (MGD)	Water Use %
368	2.40	90%
435	0.07	3%
540	0.13	5%
GCSA	0.06	2%
TOTAL	2.66	

Figure 2-3 | Historical ADD by Pressure Zone, Average 2018-2020



2.4.4 Water Demand by Customer Type

Current water use is dominated by residential customers, although the City also supplies significant commercial and industrial demand. When geolocating demands, some billing classifications didn't match the corresponding land use classification from taxlot data. In these cases, land use was assumed based on billing data classification.

The upper pressure zones have different use characteristics than the 368 Zone. Almost all customers in the 435 and 540 Zones are residential, however all multifamily customers are in the 368 Zone. Additionally, all industrial customers and most commercial customers are in the 368 Zone. The industrial demand is almost all from a few customers in the food processing and technology manufacturing industries.

Peaking factors were developed for each customer type. As irrigation is a major contributor in most peaking factors, parks and residential customers have much higher peaking factors than industrial customers who typically have a much more consistent water use.

The percentage of average daily water consumption for each customer type is presented in **Table 2-4** and **Figure 2-4**, along with peaking factors in **Figure 2-5,** to be used in future demands.

Table 2-4 | Water Consumption by Customer Type, Average 2018-2020

Customer Type	ADD (MGD)	Water Use %	MDD PF
Residential	1.26	47%	2.0
Multifamily	0.40	15%	1.5
Commercial	0.39	15%	1.8
School	0.15	6%	2.8
Industrial	0.34	13%	1.6
City	0.13	5%	2.4

Note:

1. MDD Peaking factors developed by scaling consumption data maximum month demand by 1.19 to estimate MDD. This maximum month demand peaking factor was developed from production data.

Figure 2-4 | Water Consumption by Customer Type, Average 2018-2020

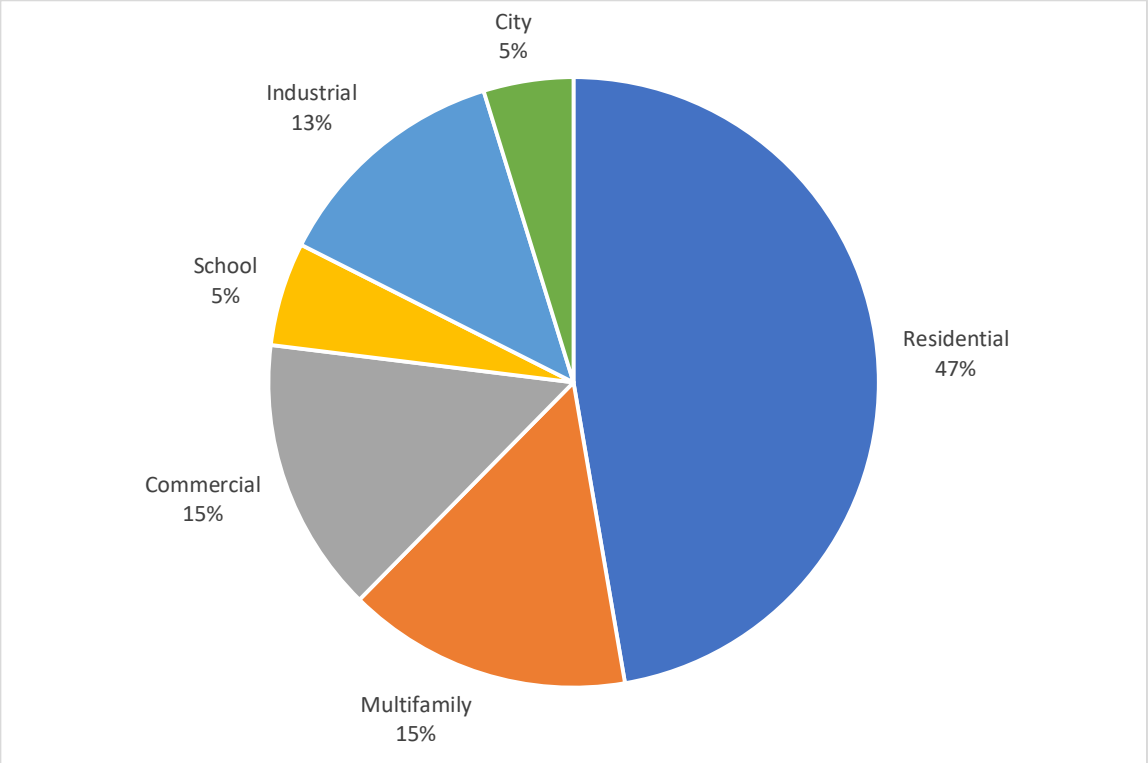
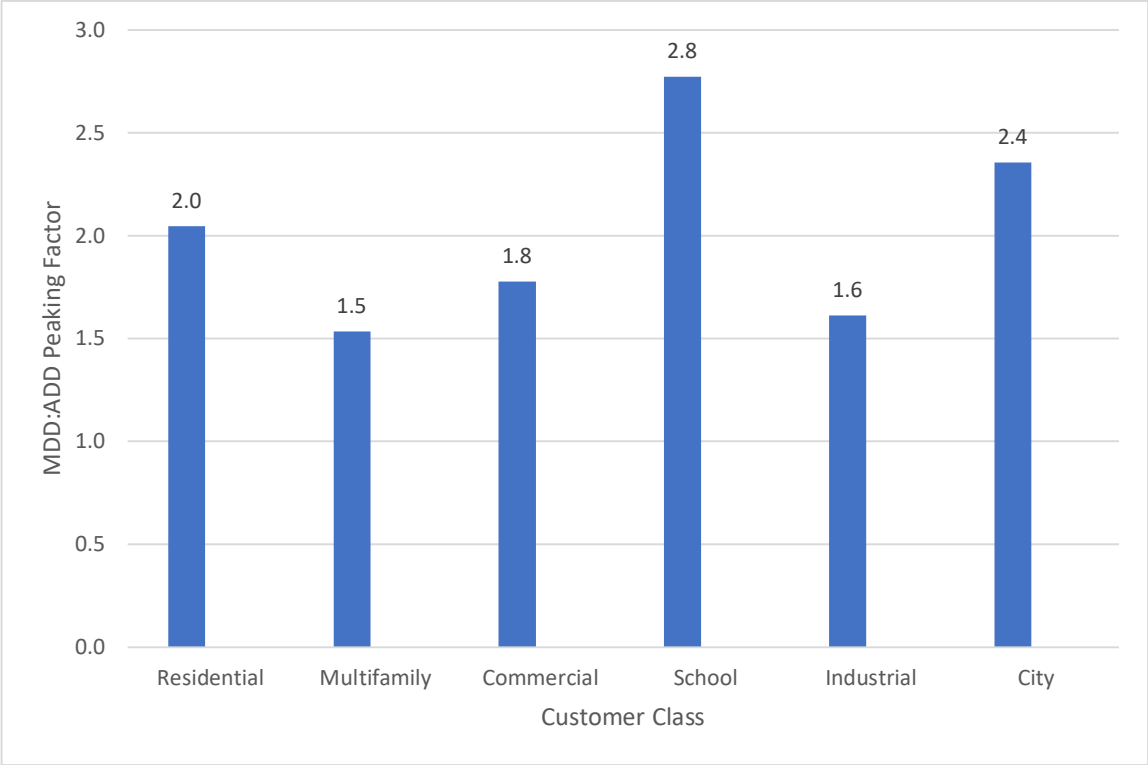


Figure 2-5 | MDD:ADD Peaking Factors by Customer Type, Average 2018-2020



Note:

1. MDD Peaking factors developed by scaling consumption data maximum month demand by 1.19 to estimate MDD. This maximum month demand peaking factor was developed from production data.

2.4.4.1 Average Residential per Capita Water Demand

Per capita ADD for residential customers is estimated based on historical residential water consumption for all customers in the City's water service area, including the GCSA, and population within the city limits as summarized in **Table 2-5** and **Figure 2-6**. Historical population and demands from the 2010 WSMP are also included for comparison. A residential ADD per capita of 70 gpcd was assumed for future residential demand projections. This is slightly higher than the recent historical average but given the limited data set and variation in historical demand, a conservative estimate is appropriate.

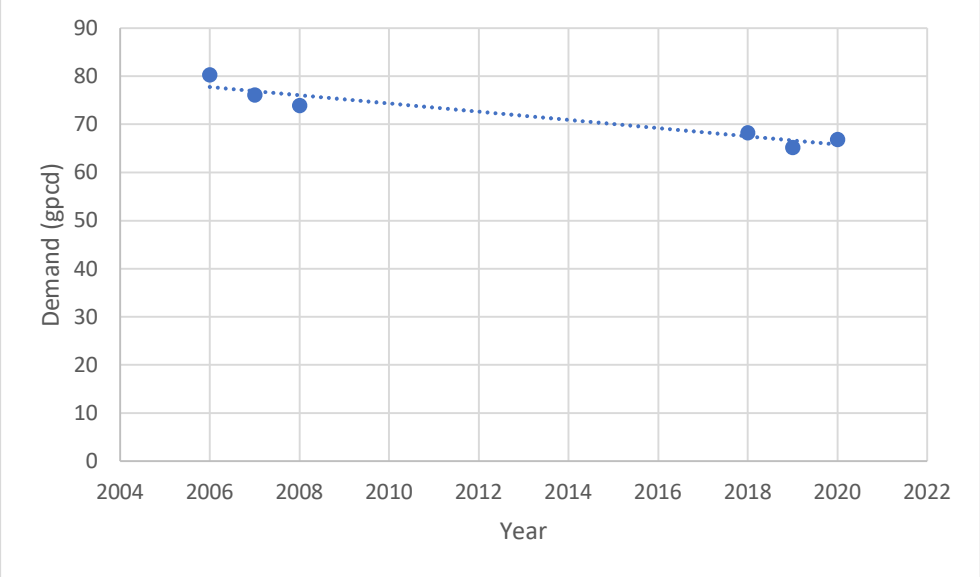
Table 2-5 | Historical Residential Demand per Capita

Year	Population	Residential + MF Demand (MGD)	Demand/Capita (gpcd)
2006, 2010 WSMP Estimate	20,380	1.64	80
2007, 2010 WSMP Estimate	20,775	1.58	76
2008, 2010 WSMP Estimate	21,465	1.58	74
2018	24,125[1]	1.65[2]	68
2019	25,180[1]	1.64[2]	65
2020	25,435[1]	1.70[2]	67
		For future projections:	70

Note:

1. City population for 2018-2020 is from the Portland State University Population Research Center (PSU PRC) population reports.
2. Residential + multifamily demand for 2018-2020 is summarized from consumption data.

Figure 2-6 | Historical Residential Demand per Capita



2.4.4.2 Average Non-Residential Water Demand per Acre

While residential water demand generally correlates well with population growth, non-residential water demands may be independent of population, particularly if system growth is not consistent across all customer classifications. To forecast future non-residential demands, an ADD per acre is estimated for different land uses based on billing records as presented in Table 2-6.

Five land use types were identified for future development: Fire Station, Elementary School, Park, Industrial, and Mixed Use/Commercial. ADD per acre was developed for each of these land uses based on existing examples. Elementary schools are considered with their adjacent parks to include irrigation demands for fields, even though taxlots may be split between park and school. Park demands are based on local parks not adjacent to schools. Future Mixed Use/Commercial development is assumed to be more like the existing downtown core than large box stores.

Therefore, a two-block estimate near Pacific Ave and Main Street was used as to develop demand per acre. Peaking factors from customer class developed in **Section 2.4.4** were used to calculate MDD.

Table 2-6 | Non-residential ADD per Acre

Development Type	Classification	Description of Data Source	ADD/Acre
Fire station	City	Fire Station at 1919 Ash St	730
Elementary School	School	Tom McCall, Harvey Clarke, and Joseph Gale Elementary Schools and adjacent parks	730
Park	City	Bard, Talisman, Hazel Sills, Knox Ridge parks[1].	1,380
Industrial	Industrial	All existing industrial demands and their corresponding taxlots.	2,550
Mixed Use/Commercial	Commercial	Sample of downtown core (approx. 2 blocks near Pacific Ave and Main Street)	1,710

Note:

1. Forest Glen and Rogers parks were not considered in this estimate because demands were not consistent with total demands and irrigation peaking seen at the other parks.
2. Industrial demand per acre in this plan is significantly higher than the industrial demand per acre calculated in the 2010 plan because this estimate uses all industrial demands, rather than a subset. As the future industrial users are unknown, a more conservative approach based on total existing industrial demands was selected.

2.4.4.3 Top Non-Residential Water Users

The following customers are the largest water users in the system, in 2020, from billing records.

Table 2-7 | Top Water Users in 2020 from Billing Records

Customer Name	Site Address	Customer Class	2020 Annual Consumption (gal)
Viasystems Technologies Corp.	1521 POPLAR ST	IND	34,360,000
Lieb Foods LLC	2550 23RD AVE	IND	25,606,000
Clean Water Services	1345 FERN HILL RD	COM	19,871,400
Rose Grove Mobile Home Park LTD	3839 PACIFIC AVE	MF	17,423,100
Westak of Oregon	3941 24TH AVE	IND	16,125,700
MGC Pure Chemicals America Inc.	701 ELM ST	IND	13,245,400
Homestead Community Inc.	1201 MOUNTAIN VIEW LN WTR	MF	12,857,000
W. Pendarvis Global Land	4115 24TH AVE (NEW BLDG)	COM	11,923,200
Forest Place Apartments LLC	3802 PACIFIC AVE3706-3834	MF	9,536,800
City of Forest Grove WTP	WTP 501 WATERCREST RD	CTY	8,394,000

2.5 Future Water Demand Forecast

Future water demand is estimated as the combination of projected residential/multifamily and non-residential demand. Residential/multifamily demand is based on population growth and

average per capita water demand. Non-residential demand is forecast based on available developable land by land use and average demand per acre.

Growth within the David Hill and Purdin Road UGB areas is based on proposed zoning and future dwelling units from the *2017 Westside Planning Program* and average persons per dwelling from the United States Census Bureau. Timing of the growth shown in this plan deviates from the 2017 report as growth has been slower in the area than previously anticipated. It is now projected that both UGB areas will be built-out within the 20-year planning window. Lower elevation development and critical infrastructure (fire station, school) were assumed to develop first.

Non-residential development and redevelopment within the existing system is based on the Employment Opportunities Analysis (EOA) developed by Johnson Economics in 2019. This report identifies taxlots available for development or redevelopment and provides 5- and 20-year City needs for industrial and mixed-use/commercial acreage.

Future water demands are forecast at 5, 10, 20, and 50 years. The UGB is anticipated to be built out within 20 years. The 50-year water demand projection assumes growth in the existing DHURA, gradual population growth which reflects potential densification and redevelopment within the existing service area after 2041, and development of the remaining non-residential land identified in the EOA.

2.5.1 Residential Densification, Housing Choices - HB 2001

In 2019, the Oregon legislature passed House Bill (HB) 2001. HB 2001 is landmark legislation that preempts local zoning regulations by doing away with the exclusively single unit residential zoning within the Portland regional urban growth boundary and within cities with a population of at least 25,000 persons elsewhere in the state. For these cities, HB 2001 requires that local zoning allow duplexes on any lot that allows a single unit dwelling as well as triplexes, quadplexes, townhouses and cottage clusters in areas zoned for single unit housing. Development Code amendments needed to comply with HB 2001 will be adopted by June 2022.

While it's clear that HB 2001 allows for higher density development within areas zoned for single unit homes, it is uncertain what impact the legislation might have on demand for public services. HB 2001 provides some guidance to cities for the purposes of utility planning. For infill areas, HB 2001 allows for a housing capacity increase of one percent over current estimates. In newly developing urban growth areas, HB 2001 allows for a housing capacity increase of three percent. Until the impacts of HB 2001 are better understood, it is assumed that the legislation will have marginal impacts on anticipated development levels, thus the potential increase in population resulting from HB 2001 was not included in the population projections in Section 2.5.2.

2.5.2 Projected Residential and Multifamily Water Demand

Future residential and multifamily water demand within the existing water service area, David Hill UGB area, Purdin Road UGB area, and DHURA is estimated based on population forecasts developed for the City's water service area by the Portland State University Population Research

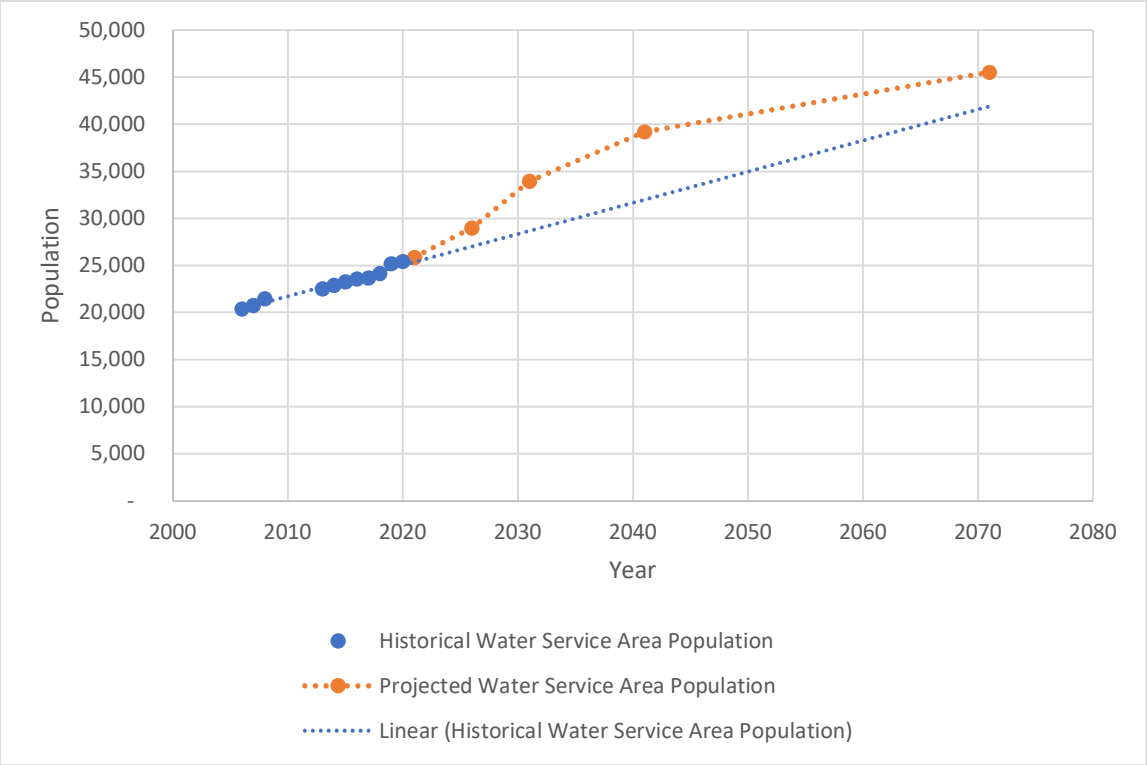
Center (PSU PRC). The PSU PRC provides annual population estimates for all Oregon cities. The population forecast for the City's water service area was part of a special 2019 study commissioned by the Portland metro area Regional Water Providers Consortium (RWPC) of which the City is a member. The population estimates from the RWPC study show an average annual growth rate (AAGR) between 1.0 and 2.0 percent through 2050. This AAGR reflects growth within the existing water service area and some growth in the UGB. Adjustments were made to this population projection based on more refined planning information specific to the GCSA and UGB development areas. This is discussed in Section 2.5.2.1.

Population growth beyond 2041 is estimated at approximately 0.5 percent annually to reflect potential densification and redevelopment within the existing service area and development of the DHURA. Historical and projected population growth is summarized in Table 2-8 and Figure 2-7.

Table 2-8 | Historical and Future Population Growth

Year	Water Service Area Population	Data Source	Average Annual Growth Rate
2006	20,380	2010 WSMP	1.9%
2007	20,775	2010 WSMP	3.3%
2008	21,465	2010 WSMP	1.0%
2013	22,518	2018 PRC Report	1.6%
2014	22,873	2018 PRC Report	1.6%
2015	23,253	2018 PRC Report	1.3%
2016	23,559	2018 PRC Report	0.5%
2017	23,672	2018 PRC Report	1.9%
2018	24,125	2018 PRC Report	4.3%
2019	25,180	2019 PRC Report	1.0%
2020	25,435	2020 PRC Report	1.7%
2021	25,877	2021 Projections	2.3%
2026	28,988	2021 Projections	3.2%
2031	33,948	2021 Projections	1.4%
2041	39,192	2021 Projections	0.5%
2071	45,517	2021 Projections	

Figure 2-7 | Historical Population Growth



Notes:

1. Blue dashed line represents average historical growth rate projection at 1.81% AAGR.
2. Orange dashed line and dots represent projected population based on 2017 Westside Planning Program, 2019 RWPC estimates, DHURA development estimates, and densification past 20 years.
3. Assumed growth rate for 2041-2071 is 0.5%.

2.5.2.1 2019 RWPC Population Estimate Adjustment

The 2019 RWPC population estimates were adjusted based on more refined development planning estimates. The following changes were made to the RWPC estimates:

- Subtract RWPC 2019 projected growth in the GCSA: The GCSA is not anticipated to supply any additional water customers in the future. Thus, the additional population associated with GCSA growth has been subtracted from the RWPC 2019 forecast population.

- Subtract partial projected growth in the David Hill and Purdin Road UGB and replace with refined projections: RWPC 2019 population estimates include portions of the David Hill and Purdin Road UGB areas. The basis for UGB growth projections in the City's *2017 Westside Planning Program* includes more detailed analysis of likely future land use including non-residential uses. Thus, the *Westside Planning Program* growth estimates are assumed to provide a more refined picture of likely future water demand for this area.

2.5.2.2 David Hill and Purdin Road UGB Areas – Residential and Multifamily

Consistent with the *2017 Westside Planning Program,* residential zoning, available land, and projected population for the David Hill and Purdin Road UGB areas is summarized in Table 2-9and allocated by year in Table 2-10. Units were calculated based on density assumed in the report, and population was calculated based on the 2040 estimate of 2.59 people per household, provided in the 2019 RWPC growth assumptions.

The Purdin Road UGB area was assumed 50% developed in 5 years and 100% developed in 10 years. All development in this area is located within the 368 Pressure Zone. The David Hill UGB area was assumed 50% developed in 10 years and 100% developed in 20 years. Development was allocated to the 368, 435, 540, and 710 pressure zones based on percentage of the total area within each zone by elevation. 710 development was assumed to begin after lower elevation development.

Table 2-9 | David Hill and Purdin Road UGB Population by Zoning

Zoning	Net Units per Acre	Net Area (acres)	Estimated Total Units	Estimated Population (units x 2.59)
Suburban Residential	1	28.5	24	62
Single Family - Low Density (R-10)	4.35	113.3	432	1,119
Single Family - Standard Density (R-7)	6.22	126.1	749	1,940
Single Family - Medium Density (R-5)	8.71	57.3	498	1,290
Residential Multifamily Low (RML)	12	8.7	103	267
Mixed-Use	Varies	22.6	144	373
David Hill & Purdin Rd Residential Units & Population			**1,950**	**5,051**

Note:
1. Additional reduction in acreage due to steep slopes not shown.

Table 2-10 | David Hill and Purdin Road UGB Projected Population

Year	Purdin Rd UGB			David Hill UGB		
	% Developed	Units	Population	% Developed	Units	Population
5	50%	587	1,521	0%	0	0
10	100%	1,174	3,041	50%	388	1,005
20	100%	1,174	3,041	100%	776	2,010
50	100%	1,174	3,041	100%	776	2,010

2.5.2.3 David Hill Urban Reserve Area

The DHURA includes higher-elevation land to the northwest of the existing UGB between Gales Creek and Thatcher Roads. Although development is not anticipated in the DHURA until after the 20-year planning horizon of this WSMP, potential growth in the area is relevant to long-term supply and storage planning. Metro policy requires adopting a concept plan for the urban reserve

area before the area is brough into the UGB; this has yet to be completed for the DHURA. A significant portion of the DHURA has ground elevations higher than the maximum service elevations for the existing water distribution system. Thus, any development in this area would require planning for new pumping and/or storage facilities to supply adequate service pressure. The DHURA concept plan will help refine any projections or facilities planned for this area.

It is assumed that future development in the DHURA would be residential with limited mixed-use neighborhood commercial. Based on the weighted average of residential (R-7 and R-10) and neighborhood mixed-use (NMU) zoning in the David Hill UGB area, future units within the DHURA are estimated at 5 net units per acre. Future developable area in the DHURA is estimated as the total area minus a 25 percent allowance for future right-of-way, approximately 183 acres. Estimated future units, approximately 915, are multiplied by 2.54 persons per unit (2019 RWPC 2050 estimate) to estimate DHURA build-out population. Growth projections would have been based off 2071 persons per unit estimates if available. However, the RWPC estimates only project to year 2050.

2.5.2.4 System Wide Residential and Multifamily Demand Growth

Summarized projected population, residential ADD, and residential MDD are listed in Table 2-11 and illustrated in Figure 2-8.

33% of the population in the 368 Zone is assumed to be multifamily. This number is derived from single family unit counts, people/unit estimates, and subtraction was used to develop a weighted peaking factor for this zone of 1.88. This peaking factor was maintained throughout the projections for the 368 Zone. The upper zones were assumed to be essentially all single family and so the SFR peaking factor of 2.0 was used for those zones.

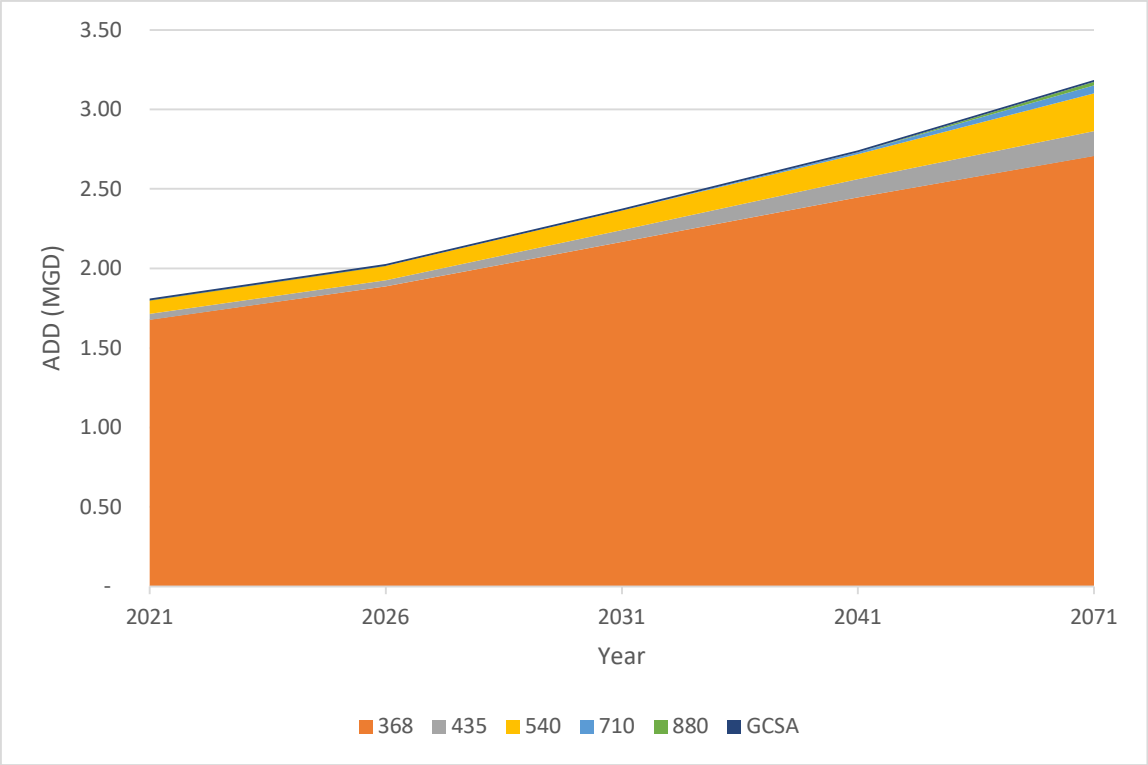
Table 2-11 | Residential and Multifamily - Projected Population and Water Demand by Zone

Population							
Year	Total	368	435	540	710	880	GCSA
2021	25,877	23,954	530	1,218	-	-	175
2026	28,988	26,958	563	1,293	-	-	175
2031	33,948	30,961	1,079	1,733	-	-	175
2041	39,192	34,954	1,633	2,258	173	-	175
2071	45,517	38,685	2,215	3,402	724	316	175
ADD (MGD)							
Year	Total	368	435	540	710	880	GCSA
2021	1.81	1.68	0.04	0.09	-	-	0.01
2026	2.03	1.89	0.04	0.09	-	-	0.01
2031	2.38	2.17	0.08	0.12	-	-	0.01
2041	2.74	2.45	0.11	0.16	0.01	-	0.01
2071	3.19	2.71	0.16	0.24	0.05	0.02	0.01
MDD (MGD)							
Year	Total	368	435	540	710	880	GCSA
2021	3.42	3.15	0.08	0.17	-	-	0.03
2026	3.83	3.54	0.08	0.19	-	-	0.03
2031	4.49	4.07	0.15	0.25	-	-	0.03
2041	5.20	4.59	0.23	0.32	0.02	-	0.03
2071	6.06	5.08	0.32	0.49	0.10	0.05	0.03

Note:

1. Projected water demands in this table do not include water loss or unmetered water use.
2. 368 Zone MDD:ADD peaking factor based on estimate of population living in multifamily or single family residential housing.

Figure 2-8 | Residential and Multifamily Demand Projection by Zone, ADD



2.5.3 Projected Non-residential Water Demand

Non-residential future demand is estimated based on historical non-residential demand and demand characteristics, projected land needs developed in the Economic Opportunity Analysis (EOA, Johnson Economics,2019), and revised available land from the 2018 Buildable Lands Inventory (BLI) and projected land use from the 2017 Westside Planning Program.

2.5.3.1 David Hill and Purdin Road UGB Areas – Non-Residential

Consistent with the *2017 Westside Planning Program,* developable mixed use and public zoned land in the David Hill and Purdin Road UGB areas is summarized in Table 2-12Error! Reference source not found.. Per-acre ADD is based on historical data of similar development types as discussed in Table 2-6, MDD peaking factors are based on demand classification as discussed in Table 2-4. All non-residential development in the David Hill and Purdin Road UGB areas is anticipated to be in the 368 Zone. It was also assumed that Mixed-Use/Commercial demand is in addition to any residential demand developed for the same acres, as the existing mixed-use classification is generally based on commercial supply only.

Table 2-12 | Projected Non-Residential UGB Water Demand

UGB Area	Development Type	Net Acres	Classification	Timing	ADD (mgd)
Purdin Road	Park	6	City	5	0.008
	School	10	School	5	0.007
	Fire Station	2.4	City	5	0.002
	Mixed Use/Commercial	19.7	Commercial	10	0.034
David Hill	Mixed Use/Commercial	2.9	Commercial	10	0.005

Note:

1. The Mixed Use/Commercial development for both Purdin Road and David Hill is shown in this table and in **Table 2-15**. It is only counted once in the demand summary.

2.5.3.2 Industrial and Mixed-Use/Commercial Land Needs

The EOA developed a land use supply and demand forecast for Industrial and Mixed-Use/ Commercial development. Supply was determined by refining the 2018 BLI and includes vacant and redevelopable land. Demand was determined through an employment need assessment. Any supply within the David Hill and Purdin Road UGB areas was replaced with the 2017 Westside Planning Program estimates, as it is a better estimate of available land in these areas.

While the EOA reports a total excess in 20-years, there is a significant mismatch of land use need (mostly mixed-use/commercial) and land use availability (mostly industrial). Therefore, it was assumed that land use would be redesignated in the future. All lands identified in the EOA are located within the 368 Zone.

The EOA developed projections for 5 and 20 years. 10-year demands were linearly interpolated from the 5 and 20-year demands. By 50 years, it was assumed that all land identified in the EOA and refined with the Westside Planning Program was developed, at the same split between Industrial and Mixed-Use/Commercial as 20-year development. Table 2-13 includes supply acreage, need acreage, and resultant demand forecast for Industrial and Mixed-Use/Commercial areas in the EOA.

Table 2-13 | EOA Demand Forecast

		Industrial	Mixed-Use/ Commercial	Total
Supply (acres)	EOA	237.1	55	292.1
	Adjusted	237.1	54.5[1]	291.6[1]
Need (acres)	5	11.1	37	48.1
	10	23.4	81.2[2]	104.6
	20	47.9	169.6[2]	217.5
	50	64.2	227.3[2]	291.6
ADD (MGD)	5	0.03	0.06	
	10	0.06	0.14	
	20	0.12	0.29	
	50	0.16	0.39	

Note:

1. 23.2 acres of commercial development located in the UGB identified by EOA replaced with 22.6 acres of commercial identified in 2017 Westside Planning, resulting in a total reduction of 0.5 acres of supply.
2. 22.6 acres of commercial located in UGB.

2.5.3.3 System Wide Non-Residential Demand Growth

Non-residential demands are not anticipated to change in the upper zones and are listed in **Table 2-14**. Growth in the 368 Zone is calculated from existing demands with growth calculated in the prior two sections. Projected Non-Residential ADD and MDD are listed in **Table 2-15** and illustrated in **Figure 2-9**.

Table 2-14 | Existing Non-Residential Demands by Pressure Zone, ADD

Zone	Commercial	Industrial	City	School	Total
368	0.38	0.34	0.07	0.15	0.94
435			0.02		0.02
540	0.001				0.001
GCSA	0.004		0.04	0.001	0.05
Total	0.39	0.34	0.13	0.15	1.00

Note:

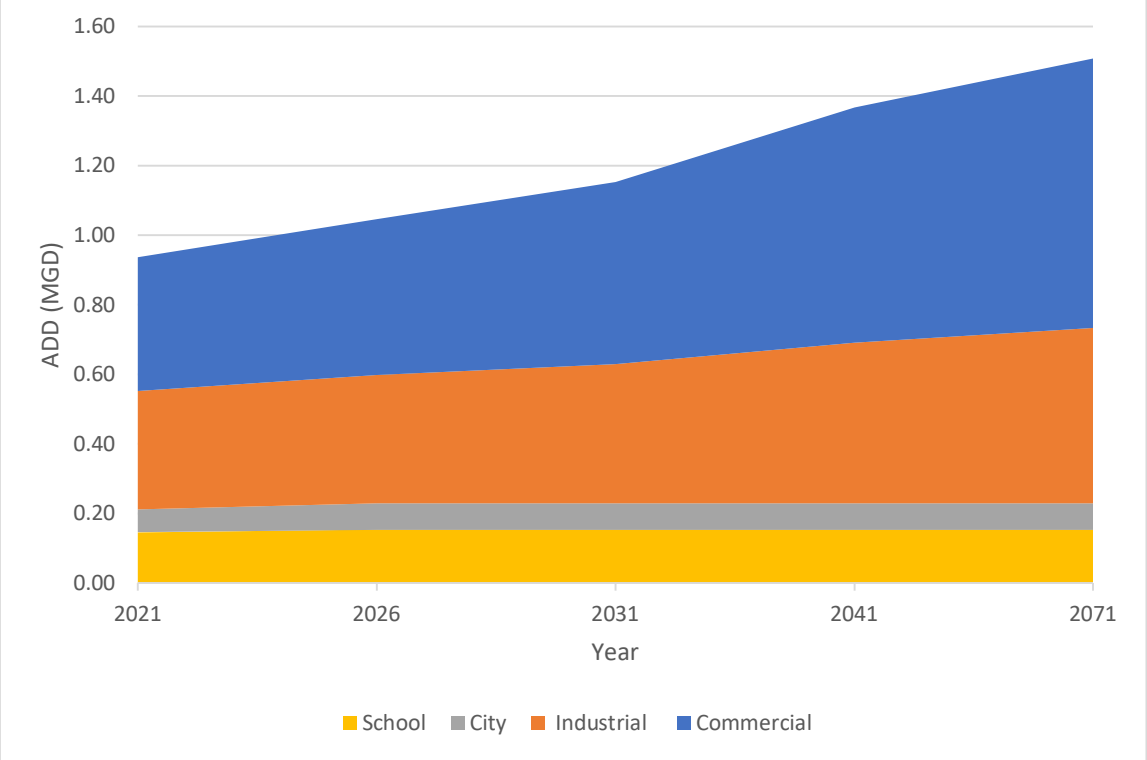
1. Water demands in this table do not include water loss or unmetered water use.
2. Water demands from average 2018-2020 metered consumption.

Table 2-15 | Non-Residential Demand Projection, 368 Zone

368 Zone ADD					
Year	Commercial	Industrial	City	School	TOTAL
2021	0.38	0.34	0.07	0.15	0.94
2026	0.45	0.37	0.08	0.15	1.05
2031	0.52	0.4	0.08	0.15	1.15
2041	0.68	0.46	0.08	0.15	1.37
2071	0.77	0.5	0.08	0.15	1.51
368 Zone MDD					
Year	Commercial	Industrial	City	School	TOTAL
2021	0.68	0.55	0.15	0.41	1.79
2026	0.8	0.59	0.18	0.43	1.99
2031	0.93	0.64	0.18	0.43	2.18
2041	1.2	0.75	0.18	0.43	2.55
2071	1.38	0.81	0.18	0.43	2.79

Note:
1. Projected water demands in this table do not include water loss or unmetered water use.

Figure 2-9 | Non-Residential Demand Projection by Class, 368 Zone



2.6 Projected Water Demand Summary

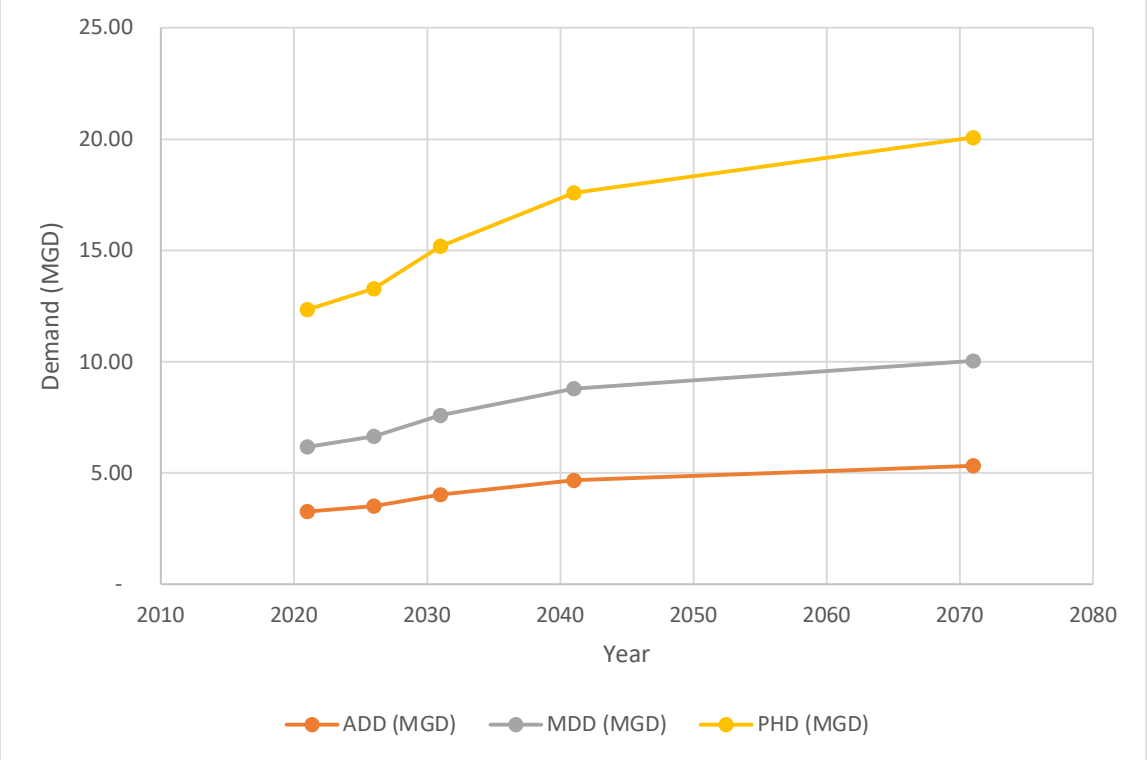
Future system demands are the sum of residential and non-residential projections, scaled to include both unmetered water use and water loss. In the Forest Grove system, unmetered water use is calculated at approximately 2%. Existing water loss is assumed at 14% with a reduction to 10% within 5 years, and then maintained at 10% through buildout. ADD and MDD are summed from existing demands and projections discussed in the prior sections, PHD is calculated using an estimated peaking factor of 2.0. **Table 2-16** and **Figure 2-10** present system wide ADD, MDD, and PHD for the 50-year projection period.

Table 2-16 | Projected Water Demand Summary

Year	Forecast Population	Assumed Water Loss (%)	ADD (mgd)	MDD (mgd)	PHD (mgd)
2021	25,877	14%	3.27	6.17	12.34
2026	28,988	10%	3.52	6.64	13.29
2031	33,948	10%	4.03	7.59	15.19
2041	39,192	10%	4.68	8.80	17.59
2071	45,517	10%	5.33	10.03	20.07

Note:
1. Assumed water loss and additional 2% unmetered use are included in the ADD, MDD, and PHD shown in this table.

Figure 2-10 | Projected Water Demand Summary



2.6.1 Water Demand by Pressure Zone

Water demand by pressure zone is used with performance criteria presented in **Section 3** to analyze the capacity of water facilities supplying each zone. Almost all non-residential and high-density developable land within the City's UGB is in the 368 Zone. The 435, 540, and future zones are primarily residential. It is assumed that the GCSA demand will remain constant over the planning period with no new customers added. Water demands by pressure zone are summarized in **Table 2-17** and **Figure 2-11.**

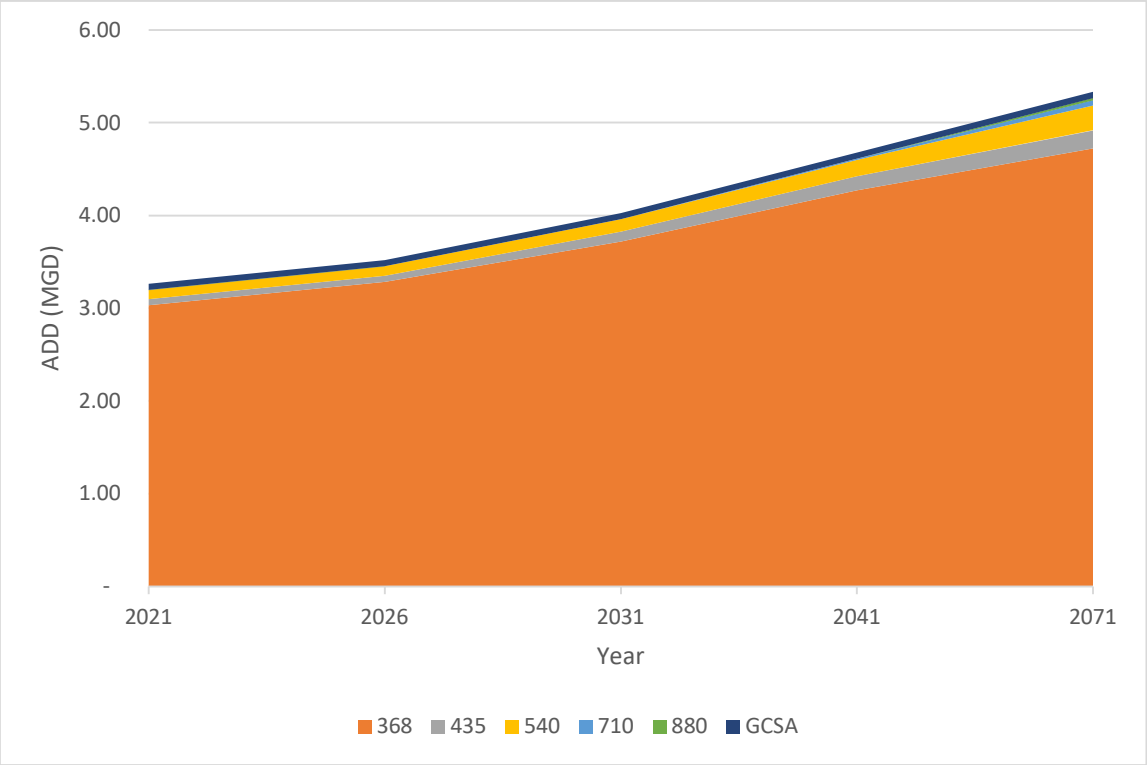
Table 2-17 | Water Demand by Pressure Zone

ADD (MGD)							
Year	TOTAL	368	435	540	710	880	GCSA
2021	3.27	3.03	0.07	0.10	-	-	0.07
2026	3.52	3.28	0.07	0.10	-	-	0.07
2031	4.03	3.72	0.11	0.14	-	-	0.07
2041	4.68	4.27	0.15	0.18	0.01	-	0.07
2071	5.33	4.72	0.20	0.27	0.06	0.02	0.07
MDD (MGD)							
Year	TOTAL	368	435	540	710	880	GCSA
2021	6.17	5.73	0.12	0.21	-	-	0.11
2026	6.64	6.20	0.12	0.21	-	-	0.11
2031	7.59	7.00	0.21	0.28	-	-	0.11
2041	8.80	8.00	0.30	0.37	0.03	-	0.11
2071	10.03	8.82	0.39	0.55	0.12	0.05	0.11

Note:

1. Demands include water loss (14% in 2021, 10% in remaining years) and 2% of additional water use for unmetered use.

Figure 2-11 | ADD by Pressure Zone



Section 3

Section 3

Planning and Analysis Criteria

3.1 Introduction

This section documents the performance criteria used for analyses of the City's water supply and distribution system. Criteria are established for evaluating water supply, distribution system piping, service pressures, and storage and pumping facilities. Recommended water needs for emergency fire suppression are also presented. These criteria are used in conjunction with the water demand forecasts developed in Section 2 to complete the analyses of the City's water supply presented in Section 4 and the distribution system in Section 5 of this WSMP.

3.2 Performance Criteria

The water distribution system should be capable of operating within certain performance limits under varying customer demand and operational conditions. The recommendations of this plan result from evaluations based on the performance criteria listed in this section and summarized in Table 3-3. The performance guidelines have been developed through review of State requirements, American Water Works Association (AWWA) acceptable practice guidelines, *Ten States Standards*, the Washington State *Water System Design Manual*, and practices of other water providers in the region.

3.3 Water Supply Capacity

As described in Section 1, the City receives most of its non-peak season, October to June, supply from the Clear Creek Watershed through the City's WTP. During the peak summer season, July through September, the City receives almost all supply from the JWC WTP and JWC Fernhill Reservoirs through the 10th Avenue Control Station.

The City's WTP draws water from five intake facilities located within the Clear Creek Watershed which is delivered through an approximately 7.8-mile RWTM. The JWC draws its water from the Tualatin River until summertime low stream flows in the Tualatin River require sourcing raw water from Barney Reservoir and Hagg Lake. Raw water is treated at the JWC WTP and pumped to transmission mains and the adjacent finished water storage tanks, the Fernhill Reservoirs. Finished JWC water is transmitted to the City through approximately 1.6 miles of 24-inch JWC TL to the 10th Avenue Control Station.

The City's overall supply capacity is impacted by each of these components: water source, raw water transmission, treatment, and finished water transmission. Current supply vulnerabilities are discussed in more detail in Section 4 including seasonal water rights limitations in the City's

watershed and finished-water transmission limitations with the City's JWC supply. The City should plan for adequate peak season (summer) supply capacity to meet the future MDD projections in each of the following: raw water source, raw water transmission, treatment, and finished water transmission.

3.4 Service Pressures and Distribution Piping

Water distribution systems are separated by ground elevation into pressure zones to provide service pressures within an acceptable range to all customers. Typically, water from a reservoir will serve customers by gravity within a specified range of ground elevations to maintain minimum and maximum water pressures at each individual service connection. When it is not feasible or practical to have a separate reservoir for each pressure zone, pump stations or PRVs are used to serve customers in different pressure zones from a single reservoir.

Most City water customers are served by the 368 Pressure Zone, which is supplied by the City's 5 MG Reservoir. The David Hill and Watercrest Pump Stations supply the David Hill Reservoir, which feeds the 540 Pressure Zone and, through a PRV, the GCSA. The 435 Pressure Zone is served by six PRVs providing water from the 540 Pressure Zone. **Figure 1-3** illustrates the existing system.

3.4.1 Normal Service Pressure

Consistent with the criteria used in the City's 2010 Water Master Plan, the acceptable service pressure range under ADD and normal operating conditions is 40 to 100 psi. Whenever feasible, it is desirable to achieve the lower limit at the highest fixture within a structure. Where mainline pressures exceed 80 psi, services must be equipped with individual PRVs to maintain their static pressures at no more than 80 psi in compliance with the Oregon Plumbing Specialty Code (OPSC 608.2).

The distribution system should be capable of supplying the PHD while maintaining service pressures of not less than 75 percent of normal system pressures, and not less than 30 psi.

3.4.2 Service Pressure in an Emergency

During a fire flow event or emergency, the minimum service pressure is 20 psi, as required by Oregon Health Authority (OHA) Drinking Water Services (DWS) and OAR 333-061-0025(7). The system should be capable of providing fire flow capacity while simultaneously delivering MDD and maintaining 20 psi throughout the distribution system. The system should meet this criterion with operational storage in the City's reservoirs depleted.

Table 3-1 | Recommended Service Pressure Criteria

Service Pressure Criterion	Pressure (psi)
Normal range, during ADD	40-100
Maximum, without PRV	80
Minimum, during emergency or fire flow	20
Minimum, during PHD	75% of normal, not less than 30 psi

3.4.3 Distribution Main Criteria

Typically, new water distribution mains should be at least 8 inches in diameter and looped to supply minimum fire flows. However, 8-inch mains may cause water quality concerns in areas with small demands. A minimum 6-inch diameter main may be acceptable as long as pressures and velocities in the pipe remain within acceptable levels. Four-inch diameter mains may be acceptable on runs less than 300 feet if no fire hydrant connection is required and future extension of the main is not anticipated. Potential water quality issues will be considered on a case-by-case basis when sizing pipes for proposed water main improvements identified during distribution system analysis.

3.5 Storage Capacity

Water storage facilities are typically provided for three purposes: operational storage, fire storage, and emergency storage. A brief discussion of each storage element is provided below. Recommended storage volume is the sum of these three components. Adequate storage capacity must be provided for each pressure zone. In some cases, storage volume can be partially or fully provided by a reservoir in a separate zone. This usually occurs for zones that do not have reservoirs and are instead supplied either by PRV or constant pressure pump station, or for zones with smaller gravity storage and if pumping is sufficiently redundant and expected to be available in an emergency.

Operational storage remains consistent with criteria established in the City's 1989, 2000, and 2010 Water Master Plans. Fire storage was updated to reflect updated Oregon Fire Code (OFC) requirements and current requirements provided by the Fire Marshall. Emergency storage capacity was increased from the 75 percent of MDD documented in prior WSMPs to 100 percent of MDD. This expanded emergency storage recommendation is due to the City's multiple supply sources and potential vulnerabilities of each as discussed in more detailed in Section 3.5.3.

3.5.1 Operational Storage

Operational storage volume is intended to address daily reservoir cycling and water system demands in excess of delivery capacity from the supply source to system reservoirs under PHD conditions. For the purpose of calculating operational storage, the 368 Zone is assumed to be supplied from both the 5 MG Reservoir at the City's WTP and the JWC supply from the 10th Avenue Control Station under peak demand conditions. The 540 Zone, 435 Zone, and GCSA are supplied

by the David Hill Reservoir. Operational storage is calculated as 25 percent of MDD for each pressure zone, which is a standard value typical of similar water systems.

3.5.2 Fire Storage

Fire storage should be provided to meet the single most severe fire flow demand within each zone. The fire storage volume is determined by multiplying the recommended fire flow rate by the expected duration of that flow consistent with the OFC and the Insurance Services Office (ISO) Supply Gradings for Public Protection classification. Specific fire flow and duration recommendations are discussed later in this section.

3.5.3 Emergency Storage

Emergency storage is provided to supply water from storage during emergencies such as pipeline failures, equipment failures, power outages or natural disasters. The amount of emergency storage provided can be highly variable depending upon an assessment of risk and the desired degree of system reliability. The City has elected to follow the guidelines in the 2020 *Washington Water System Design Manual* (Washington Guidelines) for determining the emergency storage volume of the water system. The Washington Guidelines recommend emergency storage equal to one day of MDD, which is an increase from the 2010 WSMP emergency storage criteria of 75 percent of MDD. The City has made this decision based on the following reasons:

- *The City is heavily reliant on the JWC in the summer and additional emergency storage will provide a buffer for a JWC outage.* If the JWC supply, including treatment, storage, and transmission, is not available to the City during the high demand season, then the City emergency storage is limited to in system storage and approximately 0.52 mgd from the City's WTP. However, the City WTP supply at this rate is approximately less than 5% of the projected 2041 total MDD and thus provides limited benefit. Increasing the emergency storage volume requirements reduces the immediate impact of a JWC outage.

- *The existing JWC and City systems are vulnerable to seismic events; additional emergency storage will be constructed current seismic standards and more likely to be available after a seismic event.* As discussed later in Section 6, the 2020 Water System Seismic Resiliency Plan (SRP, InfraTerra, 2020, Appendix H) states that there is a 16 to 22 percent probability of an earthquake with magnitude 8.5 or greater along the Cascadia Subduction Zone (CSZ) in the next 50 years (Goldfinger et al., 2016). Such an earthquake will likely pose a significant risk to the JWC and Forest Grove Water systems, including:

    - JWC evaluations have identified significant seismic deficiencies at the existing JWC WTP, excluding the recent expansion. The CSZ may result in the loss of JWC's ability to produce finished water.

    - The existing 24" and 72" JWC Transmission Lines are subject to damage from the CSZE that may result in breaks or leaks that will have to be repaired before they are able to

convey finished water from the JWC Fern Hill Reservoirs and/or the JWC WTP to the City.

- The City's existing raw water transmission line is subject to breaks and leaks caused by CSZ event along a majority of its alignment that would result in the loss of raw water supply to the City's WTP.
- The City's existing distribution system is also subject to damage from the CSZ that would have to be repaired before water could be conveyed through the system from the reservoirs
- This WSMP and the SRP have identified capital improvement projects to address seismic resiliency improvements to the City's water system, while the JWC is currently developing their Water System Master Plan, which will also include seismic resiliency improvements to the JWC system. The seismic resiliency improvements that will likely be required for both systems will be expensive and may take a long time complete due to the high cost.

One MDD of emergency storage is a somewhat conservative approach which will be reviewed as part of future reservoir preliminary design phases. During the preliminary design phase, some of the factors that may be reviewed include:

- Comparison of this WSMP projected growth to the future water demand
- Whether large industrial or commercial users locate to the City, thus adjusting system needs
- Impact on water quality
- Impact on future rates
- Risk assessment
- Completed and planned seismic resiliency improvement projects

3.5.4 JWC Contractual Storage Requirements Comparison

The JWC supply contracts require partner agencies to provide three times the average take from the JWC in regional and partner-controlled storage. This storage volume refers to total storage (including emergency, fire, and operational) in all zones.

The existing regional and City-controlled storage will be compared against this benchmark and the emergency storage criteria to determine the range of emergency storage deficiencies. Emergency storage criteria considerations are:

- Emergency Storage – 1.0 x MDD in City and regional storage

- JWC Contract guidelines – 3.0 x average take from the JWC in City and regional storage

3.6 Pump Station Capacity

Pumping capacity requirements vary depending on how much storage is available, the number of pumping facilities serving a pressure zone, and the zone's maximum fire flow requirement. Pumping recommendations are based on firm capacity which is defined as a pump station's capacity with the largest pump out of service.

3.6.1 Pump Station Supplying Pressure Zone with Gravity Storage

For pump stations supplying pressure zones with gravity storage available, the station must have adequate firm capacity to supply MDD for the zone.

3.6.2 Pump Station Supplying Constant Pressure to Zone

Although it is desirable to serve water system customers by gravity from storage, constructing and maintaining a reservoir for a small group of customers may be prohibitively expensive and lead to water quality issues associated with slow reservoir turnover during low demand times. Constant pressure pump stations supply a pressure zone without the benefit of storage and are commonly used to serve customers at the highest elevations in a water service area where only an elevated reservoir would be capable of providing the necessary hydraulic head to achieve adequate service pressures by gravity. Pump stations supplying constant pressure service should have firm pumping capacity to meet PHD while simultaneously supplying the largest fire flow demand in the zone.

Constant pressure pump stations are only recommended for areas with low water demand and limited potential for future looping with adjacent pressure zones.

3.6.3 Standby Power

Standby power facilities are needed for constant pressure stations and for pump stations serving pressure zones with inadequate emergency storage capacity. Standby power is typically provided in the form of an on-site backup generator sized to operate the pump station at firm capacity with automatic transfer switches and on-site fuel storage.

3.7 Fire Flow Recommendations

While the water distribution system provides water for domestic uses, it is also expected to provide water for fire suppression. The amount of water required for fire suppression purposes is associated with the building size and type or land use of a specific location within the distribution system. Fire flow requirements are typically much greater in magnitude than the MDD in any local area. Adequate hydraulic capacity must be provided for these potentially large fire flow demands. Recommended fire flow requirements by land use type are based on the 2019 OFC and the ISO Supply Gradings for Public Protection Classification (PPC).

The ISO PPC ratings are used to inform property insurance rates throughout the United States. Public water system performance accounts for approximately 30 percent of a City's PPC rating. Overall, City ratings are not impacted by individual properties with fire flow demands over 3,500 gpm.

Additionally, the 2019 OFC (B106) limits required fire flow to a maximum of 3,000 gpm for buildings in protected areas with adequate and reliable water systems, such as the City's system. Therefore, the maximum fire flow considered within the Forest Grove Service Area is 3,000 gpm.

In 2016, the City completed an *Industrial Zone Development Analysis (HDR)*. This analysis included a review of the City's fire flow criteria by land use type. Recommended fire flows from the 2016 study are used for this WSMP analysis. Fire flow requirements by land use type are summarized in Table 3-2.

3.7.1 Low Density - Single-Family and Duplex Residential

The OFC guidelines specify a minimum fire flow of 1,000 gpm for single-family and two-family dwellings with square footage less than 3,600 square feet. For residential structures larger than 3,600 square feet, the minimum fire flow requirement is 1,750 gpm.

For the purposes of this WSMP, distribution piping fire flow capacity will be tested in the water system hydraulic model with a minimum requirement of 1,750 gpm to accommodate the range of potential future residential development in the City. Where deficiencies are identified in the existing system based on this 1,750 gpm requirement, existing development will be evaluated to determine if a 1,000 gpm fire flow requirement is appropriate for the local area.

3.7.2 Medium Density Residential

Based on the OFC requirements, a required fire flow of 2,000 gpm is recommended for medium density residential properties consistent with the City's *2016 Industrial Zone Hydraulic Analysis (HDR)*.

3.7.3 High Density Residential, Commercial, Industrial, and Institutional

A 3,000 gpm fire flow is recommended for high density residential, commercial, and industrial development consistent with OFC maximum fire flow guidelines. This maximum fire flow requirement is also appropriate for institutional facilities, although 2,500 gpm fire flow may be allowed for some public facilities.

Recommended fire flow requirements by land use type are summarized in Table 3-2 and are consistent with the *2016 Industrial Zone Hydraulic Analysis (HDR)*.

Table 3-2 | Recommended Fire Flow Summary

Land Use Designation	Recommended Available Fire Flow (gpm)	Fire Flow Duration (hours)
Residential		
Low density	1,750	2
Medium density	2,000	2
High density	3,000	3
Commercial		
Town Center District	3,000	3
Commercial auto	3,000	4
Commercial heavy	3,000	4
Commercial neighborhood	3,000	3
Industrial		
Light industrial	3,000	3
General industrial	3,000	4
Institutional		
Public	2,500	2
Semi-public	3,000	4

Table 3-3 | Performance Criteria Summary

Water System Component	Evaluation Criterion	Value	Design Standard/Guideline
Water Supply	Peak Season (Summer) Capacity	MDD[2] from reliable sources	Washington Water System Design Manual
Service Pressure	Normal Range, during ADD[1]	40-100 psi	City of Forest Grove 2010 Water Master Plan
	Maximum, without PRV	80 psi	Oregon Plumbing Specialty Code 608.2
	Minimum, during emergency or fire flow	20 psi	OAR 333-061
	Minimum, during PHD[2]	75% of normal, not less than 30 psi	Murraysmith recommended
Distribution Mains	Velocity during PHD[3] or fire flow	Not to exceed 10 fps	AWWA M32
	Minimum Pipe Diameter	8-inch recommended for fire flow, 6-inch may be acceptable for short loops, 4-inch may be acceptable for mains less than 300 feet with no fire hydrants	Murraysmith recommended
Storage	Operational Storage	25% of MDD[2]	2010 Water Master Plan
	Fire Storage	Zone Dependent	2019 Oregon Fire Code B106
	Emergency Storage	Criteria 1 - 2xMDD (City + Regional Storage) Criteria 2 - 3x average JWC take (City + Regional)	2020 Washington Water System Design Manual, JWC contract storage guidelines
Pump Stations	Supplying Storage - Required Capacity	MDD[2] at firm capacity	Washington Water System Design Manual
	Supplying Constant Pressure to Zone[4] - Required Capacity	PHD[3] + Fire Flow	Washington Water System Design Manual
	Backup Power - Supplying Storage	Manual transfer switch and connection for portable generator	Murraysmith recommended
	Backup Power - Critical Facilities and Sole Supply to Zone	Automatic transfer switch and on-site generator and fuel storage	Murraysmith recommended
Required Fire Flow and Duration	Low Density - Single Family and Duplex Residential <= 3,600 sq ft	1,000 gpm for 1 hour	2019 Oregon Fire Code Appendix B, Insurance Services Office (ISO) Supply Gradings for Public Protection

Water System Component	Evaluation Criterion	Value	Design Standard/Guideline
	Single Family and Duplex Residential >3,600 sq ft	1,750 gpm for 2 hours	Classification (PPC), 2016 Forest Grove Industrial Zone Development Analysis
	Medium Density Residential	2,000 gpm for 2 hours	
	Public	2,500 gpm for 2 hours	
	High Density Residential, Commercial, Industrial, Semi-Public Institutional	3,000 gpm for 3 or 4 hours	
	368 Zone	3,000 gpm for 4 hours	
	435, 540, 710, 880	2,000 gpm for 2 hours	

Note:

1. ADD: Average daily demand, defined as the average volume of water delivered to the system or service area during a 24-hour period = total annual demand/365 days per year.
2. MDD: Maximum day demand, defined as the maximum volume of water delivered to the system or service area during any single day.
3. PHD: Peak hour demand, defined as the maximum volume of water delivered to the system or service area during any single hour of the maximum demand day.
4. There are no existing zones in the Forest Grove distribution system served solely from a constant pressure pump station. Potential future development of the Purdin Road Planning Area and the northernmost David Hill Planning Area which is too high in elevation to be served by gravity from the existing David Hill Reservoir may require constant pressure pumping.



Section **4**

Section 4

Water Supply Analysis

4.1 Existing Supply

The City's finished water supply is provided from two sources: the City's WTP with raw water supply from the Clear Creek watershed and the JWC regional WTP with raw water supply from the Tualatin and Trask River systems. The JWC is jointly owned by the cities of Hillsboro, Beaverton, and Forest Grove, and the TVWD. Both WTPs rely on water rights that are regulated off in the summer due to low in stream flows. The City's WTP can only operate if there is water available in the stream while the JWC can release water from stored impoundments, Barney Reservoir and Hagg Lake (Scoggins Reservoir), when in stream flows are too low. Therefore, the City currently relies on the City WTP primarily in the winter and the JWC WTP primarily in the summer.

4.1.1 Forest Grove WTP Supply

The City's existing WTP uses conventional filtration to treat raw water from the Clear Creek watershed, a tributary of Gales Creek located northwest of the City. The raw water is conveyed from intakes in the Clear Creek watershed approximately 7.8 miles southeast to the Forest Grove WTP through a 16-inch diameter CCP transmission main (the RWTM). See Plate 1 in Appendix A for system map. Typically, the RWTM flows by gravity to the WTP to supply up to 2.7 mgd if flows are available in the creek. The Raw Water PS can increase flows up to 3.7 mgd. Finished water is stored on the WTP site in the City's 5.0 MG Reservoir, which acts as the WTP clearwell and provides service pressure for the City's 368 Pressure Zone.

4.1.2 Joint Water Commission Supply

The JWC treats raw water from the Tualatin River. Supply from the Tualatin River is limited in the dry summer season due to low in-stream flow. During the summer, the JWC raw water supply is released from local impoundments, Barney Reservoir and Hagg Lake (Scoggins Reservoir), and withdrawn by the JWC from the Tualatin River for treatment at the JWC WTP. Finished water is supplied to the City directly from the JWC WTP or from the two JWC 20 MG Fern Hill Reservoirs through approximately 8,200 linear feet of 24-inch diameter JWC TL, which is jointly owned by the cities of Forest Grove and Hillsboro. Finished JWC water enters the City's system at the 10th Avenue Control Station (see Plate 1 in Appendix A). The City owns 10 mgd of the total 85 mgd treatment capacity of the JWC WTP.

4.1.3 Emergency Supply Interties

The City maintains a single 6-inch emergency intertie with the City of Cornelius distribution system, located on Heather Street at the city limits (see Plate 1 in Appendix A). This intertie has not been exercised in the past 10 years and capacity estimates are not available for supply in either direction. It is expected that supply will be limited and dependent on operating conditions of the two systems when an emergency occurs. Cornelius purchases their non-emergency water supply from the City of Hillsboro through three connections to the 72-inch diameter JWC NTL which is owned by the City of Hillsboro, the City of Beaverton, and TVWD.

The City of Cornelius is planning a second emergency intertie with the City's water system in N Adair Street, east of its intersection with Yew Street. According to Cornelius's *2017 Water Master Plan*, the project will connect an existing 12-inch line in N Adair Street in Cornelius to an existing 10-inch line in Adair Street in Forest Grove.

The City is currently designing and has in place an emergency intertie IGA connection directly to the 72-inch JWC NTL at an existing blind flange near Mountain View Lane and Heather Street near the Forest Grove-Cornelius city boundary. Although the City is a partner agency in the JWC, the City does not own capacity in the 72-inch JWC NTL. As an emergency intertie, the proposed Heather Street Intertie is limited to short term emergency use and to supplement fire supply. Non-emergency supply capacity in the 72-inch JWC NTL may become available for lease from Hillsboro to supply the City's system although the timing of this is unclear. More discussion on the proposed Heather Street Intertie and supply transmission within the City water system is included in Section 4.4 and Section 5.

4.1.3.1 Evaluation of Groundwater Source for Emergency Use

As part of this master planning effort, GSI Water Solutions, Inc (GSI) evaluated existing groundwater wells within 2 miles of the City as a potential emergency water supply, primarily in the event of a Cascadia Subduction Zone Earthquake (CSZE). The full report of this analysis is included as Appendix C. The evaluation followed Environmental Protection Agency (EPA) and Federal Emergency Management Agency (FEMA) emergency water capacity recommendations of 1 gallon per person per day. To meet this estimated emergency demand, the City would need to develop 2 to 4 wells at 10 to 30 gpm production rates within the next 10 years. This well development would be in addition to continued City investment in seismic improvements throughout the system to meet long-term Oregon Resilience Plan (ORP) recovery goals.

Two wells, WASH 10597 and WASH 60859, were identified for further study based on the quality of well data, location relative to geohazards, and proximity to Catastrophe Reception Centers and backbone infrastructure. The existing production rates of the two wells are 320 gpm and 72 gpm, respectively. Further recommendations for the identified wells include:

- Add auxiliary power supply
- Add disinfection equipment
- Evaluate seismic resilience

- Develop agreements with well owners addressing site visits, contamination studies, and water rights

At this time, the City has elected to pursue the development of emergency water supplies as a separate project, therefore the use of emergency groundwater supplies will not be addressed further in this report. A future emergency water supply project should include evaluating sources of emergency water supply such as new wells, packaged water treatment plants, and more detailed review of existing groundwater wells.

4.2 Water Rights

The City has water rights on Clear Creek, Roaring Creek, Gales Creek, and the Tualatin River. **Table 4-1** details the City's live water rights.

Table 4-1 | Live Water Rights

Source	Priority Date	Certificate	Type	Authorized Rate	
				cubic feet per second (cfs)	mgd
Clear Creek	3/29/1917	2194	Municipal	0.80	0.52
Clear Creek	4/16/1935	13471	Municipal	1.00	0.65
Clear Creek	7/27/1939	13797	Municipal	1.00	0.65
Gales Creek	2/14/1947	T-11677	Municipal	4.46	2.88
Roaring Creek	4/28/1976	92949	Municipal	2.43[1]	1.57[1]
Clear Creek	4/28/1976	92949	Municipal	2.83[1]	1.83[1]
Tualatin River	4/28/1976	85916	Municipal	33.0	21.3

Note:
1. Combined authorized rate of both rights under certificate 92949 not to exceed 4.46 cfs (2.88 mgd).

In the winter, in-stream flows are sufficient to allow the City to use their full water rights. In the summer, however, available raw water in the Clear and Roaring Creeks is typically reduced to a minimum of the City's 1917 water right, or 0.52 mgd. Remaining finished water supply to the City distribution system comes from the JWC.

Although the City holds a water right on Gales Creek, there is currently no intake. The City transferred this Gales Creek right (formerly certificate 85513) to a new point of diversion (POD) in 2013 which was approved by the State under transfer application T-11677. The new POD is at the JWC Springhill Pump Station intake facility. At this time, the water can be taken at the new POD between October 1 and May 31, but not between June 1 and September 30 because the City has not installed a suitable stream-flow gaging station at the original POD per the Final Order. In addition, during the period of June 1 to September 30, there must be sufficient water in Gales Creek at the original POD for water to be withdrawn at the new POD. Full beneficial use of the water at the new POD shall be made on or before October 1, 2035.

The JWC's Tualatin River raw water intake is also limited due to in-stream demands during this dry summer season. Typically, from mid to late May through October, it is assumed that JWC is regulated off the Tualatin River due to its junior water right. Therefore, during this period all raw water supply to the JWC WTP is provided by the two local impoundments which are Hagg Lake (Scoggins Reservoir) and Barney Reservoir. In 2018 and 2019 the raw water supply from the two local storage impoundments continued into November and December respectively.

4.2.1 Stored Water Rights

The City holds water rights to stored water in the two JWC raw water supply impoundments, Barney Reservoir and Hagg Lake (Scoggins Reservoir). Hagg Lake is located approximately five miles southwest of the City and has a water elevation of 306 feet at maximum storage capacity. At a surface elevation of more than 1,600 feet, Barney Reservoir is situated about 15 miles southwest of the City. **Table 4-2** summarizes the City's stored water rights. During the summer months, once Washington County's Watermaster has ordered users to stop using Tualatin River flow as a raw water supply source, the JWC begins releasing raw water from the two local impoundments.

The City has a "buy-back" option for stored water in the Barney Reservoir that is currently owned by TVWD (see **Table 4-2**). To initiate the buy-back option, the City must provide written notice of their intent to buy-back the stored water right in Barney Reservoir from TVWD. The transfer of the stored water rights in Barney Reservoir from TVWD to the City may take up to four years from when the City submits the written notice. The Barney buy back option has no expiration date for the City to initiate the buy-back option or the cost to purchase the stored water rights in Barney Reservoir. The text of the Buy-Back Option is included in **Appendix D**.

Table 4-2 | Forest Grove Stored Water Rights – Source Water to JWC WTP

Reservoir	Stored Water Rights		Potential Maximum Release Season Average Daily Supply of Total Storage (MGD)
	acre-ft (AF)	MG	
Barney Reservoir	500	163	0.9
Barney Reservoir Buy-Back Option	800	260	1.4
Hagg Lake	4,500	1,465	7.7
Total (Without buy-back)	5,000	1,628	8.6
Total (Including buy-back)	5,800	1,888	9.9

Note:

1. Release season average daily supply of total storage assumes a release season of 190 days (see **Section 4.3.1.2**) and an initial total stored water volume equal to the full water right. This number has not been reduced by loss/reduction factors (see **Section 4.3.1.2**).

4.2.1.1 Historical Stored Water Release Rates

Typically, water is released from JWC impoundments at lower rates in the early summer and fall, with the highest release rates in August. **Table 4-3** presents release rates for the City from the 2018 and 2019 seasons and the combined release factors. Currently, the Barney Reservoir is used

later in the season at much less than the full available water right as shown in Table 4-2. Therefore, a combined release factor will be used to predict total availability. The combined release factors are calculated by dividing the average monthly release rate by the overall average release rate for the actual release period for each year. The combined release factor will be used in the water supply analysis to predict future raw water availability.

Table 4-3 | Historical Release Rates

Month	Hagg Lake (Scoggins Reservoir) 2018/19 Avg Release Rate (mgd)	Barney Reservoir 2018/19 Avg Release Rate (mgd)	Average Combined Release Rate (mgd)	2018/19 Combined Release Factor[1]	2010 WMP Release Factor[2]
May	0.49	0	0.49	0.2	0.4
June	1.65	0	1.65	0.8	0.8
July	2.66	0	2.66	1.3	1.2
August	2.99	0	2.99	1.5	1.5
September	1.83	0.08	1.91	1.0	1.4
October	1.36	0.06	1.42	0.7	0.7
Post-October	1.39	0.04	1.44	0.7	0
Release Season Average	1.96	0.03	1.99	-	-

Note:

1. Combined Release Factors are calculated by dividing a given months average release rate by the overall average release rate for the season. Release season for this calculation is from the start of release through the last day of release, rather than the release days within the regulation period.
2. Not used in this analysis – shown for reference.

4.3 Water Supply Analysis

A water supply system must have adequate source water, treatment, and transmission to serve customers and accommodate projected future growth. Any one of these components may be a limiting factor in the water supply system's capacity. The following analysis shows raw water source capacity for the City's water rights and finished water supply capacity in the City and JWC WTPs and transmission facilities.

Source Water - The City likely has adequate water rights and existing nominal raw water supply capacity to meet projected MDD through the 50-year planning horizon. Hydrologic changes, such as drought, are likely to continue to impact stream flows in the Tualatin Basin which will mean a longer release season for stored raw water with the JWC and potentially shorter operating season for the City's WTP if available flow from the Clear Creek watershed declines earlier in the year.

Treatment – The City has sufficient treatment in the City's WTP and the JWC WTP to meet future demands through the 50-year planning horizon. Available flow from the Clear Creek watershed is the limiting factor for finished water supply from the City's WTP which is at its lowest annual capacity during the highest annual system demand. This capacity challenge along with aging infrastructure at the WTP is a key consideration for long-term investment in this facility. It is

recommended that the City develop a facility plan for the WTP which includes evaluations of facility condition and operation.

Transmission and Storage – The City currently has sufficient transmission to meet MDD but will likely need expanded capacity from the JWC within 5 years. The City relies on JWC finished water supply to meet peak summer demands. This finished water supply is currently vulnerable due to the single 24-inch diameter JWC TL connecting the City system to the JWC.

The existing 5 MG Reservoir acts as the clearwell for the City's WTP, provides terminal storage for the JWC finished water supply, and pressurizes the 368 Zone when JWC supply is reduced. This critical facility should be replaced with a seismically resilient structure with adequate capacity and redundancy to meet future storage requirements. Storage limitations are discussed further in Section 5.3.

4.3.1 Raw Water Capacity Analysis

4.3.1.1 Forest Grove WTP – Clear Creek

Source water from the Clear Creek intakes is limited during the dry summer season when in-stream flows are low and the City may be "regulated off" the creeks by the Watermaster. In the City's *2010 Water Master Plan* seasonal limitations in raw water flow were estimated as 1.5 mgd. More recently, seasonal limitations have been closer to 0.55 mgd (2013-2018 historical average low monthly supply rate). As discussed in Section 4.2, it is expected that the City will typically retain Clear Creek supply in the summer through its 1917 water right (2194) at a rate of 0.52 mgd. The City should plan for a reduced source water availability of 0.52 mgd.

4.3.1.2 JWC Supply – Stored Water Rights and Available Water

The City relies on the JWC supply system to meet peak summer demands. As a junior water right, the City's 1976 Tualatin River water right that helps supply the JWC WTP is assumed to be regulated off during this period. Instead, the JWC releases raw water from Hagg Lake (Scoggins Reservoir) and Barney Reservoir storage impoundments. The released raw water from the storage impoundments then flows to the Tualatin River where it is withdrawn by the JWC for treatment at the JWC WTP.

Impoundment release data from2018 and 2019 show a possible trend towards longer storage release seasons ending later in the fall. Based on 2018 and 2019 data, the release season is assumed to be 190 days when evaluating future raw water availability.

In 2019, the raw water available in both reservoirs at the beginning of the release season was approximately 85 percent of the City's stored water rights. However, between 2015 and 2019, the City has used on average less than 30 percent of its water rights capacity in Hagg Lake (Scoggins Reservoir) and less than 10 percent of water right capacity in Barney Reservoir. While the 2019 initial stored volume of 85 percent of the City's stored water right capacity still exceeds the current

summer demand, the City may need to plan for reduced initial capacity from the JWC storage impoundments in the future.

Water released from Barney and Hagg Lake (Scoggins Reservoir) travels down the Tualatin River before it reaches the JWC WTP intake. Some of the released flow is lost or reduced before reaching treatment and a smaller percentage is lost through treatment and transmission. Loss/reduction factors described in the City's *2010 Water Master Plan* are applied here to estimate the supply benefit gained from stored raw water rights. Loss/reduction factors are also applied to the Barney Reservoir buy-back option storage.

- Barney Reservoir – 24 percent reduction of total storage volume
  - Two percent dead pool – water level too low to be accessed
  - 15 percent fish flow
  - Two percent blow-by
  - Five percent transmission & treatment loss
- Hagg Lake (Scoggins Reservoir) – 7 percent reduction of total storage volume
  - Two percent blow-by
  - Five percent transmission & treatment loss

4.3.1.3 Drought Considerations

Quantifying future drought potential is challenging and research is continually evolving. Granular climate model data was not available for this Plan. A 20 percent reduction in available raw water was chosen as a drought planning assumption based on City staff analysis of historical fill data for Hagg Lake (Scoggins Reservoir) between 1976 and 2020 and Barney Reservoir between 1999 and 2020.

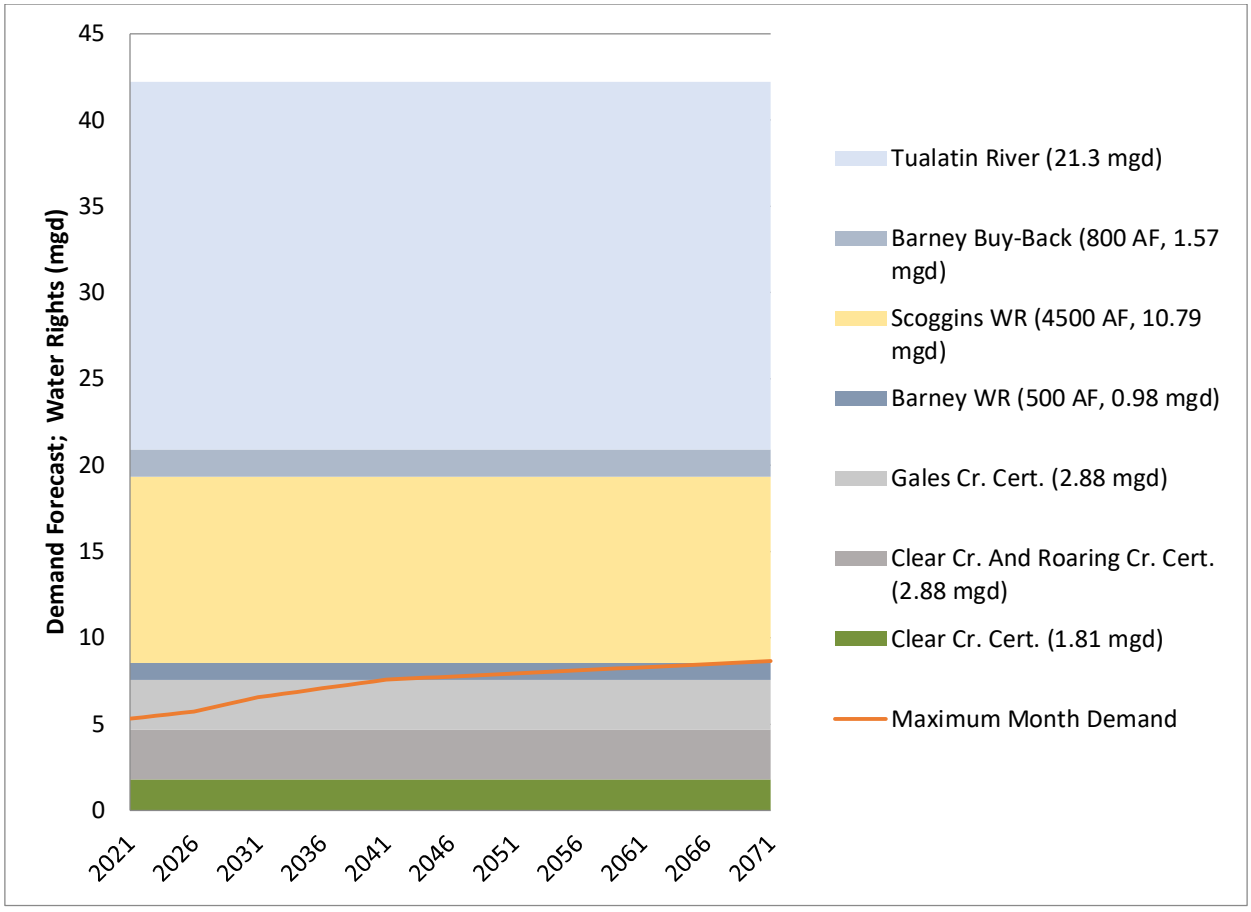
Both Barney and Hagg Lake (Scoggins Reservoir) have filled to over 85 percent by May 1 every year of data except 2001. In 2001, an extreme drought reduced fill at the beginning of the summer to approximately 50 percent. This 50 percent fill is four to five standard deviations away from the mean fill and thus represents an extreme condition beyond what is anticipated for future non-curtailed supply planning needs based on available information at the time of this Plan. It is recommended that the City consider potential drought conditions when evaluating long-term supply strategy scenarios summarized at the end of this section.

4.3.1.4 Raw Water Capacity Findings

The City has adequate water rights to supply anticipated growth through 2071, even when seasonal limitations are considered, including a blanket 20% drought reduction (**Figure 4-1** and **Figure 4-2**). When looking at month by month supply, the City is most vulnerable during early and late summer, especially under drought conditions (**Figure 4-3** and **Figure 4-4**). However, barring an extreme drought or other extenuating circumstances, the City has sufficient raw water rights.

The Water Supply Study, recommended in **Section 4.4.4**, should consider raw water supply vulnerabilities due to seasonal limitations and drought. Additional finished water treatment and transmission limitations are discussed in **Section 4.3.2.1**.

Figure 4-1 | Full Water Rights, Assuming No Seasonal Limitations

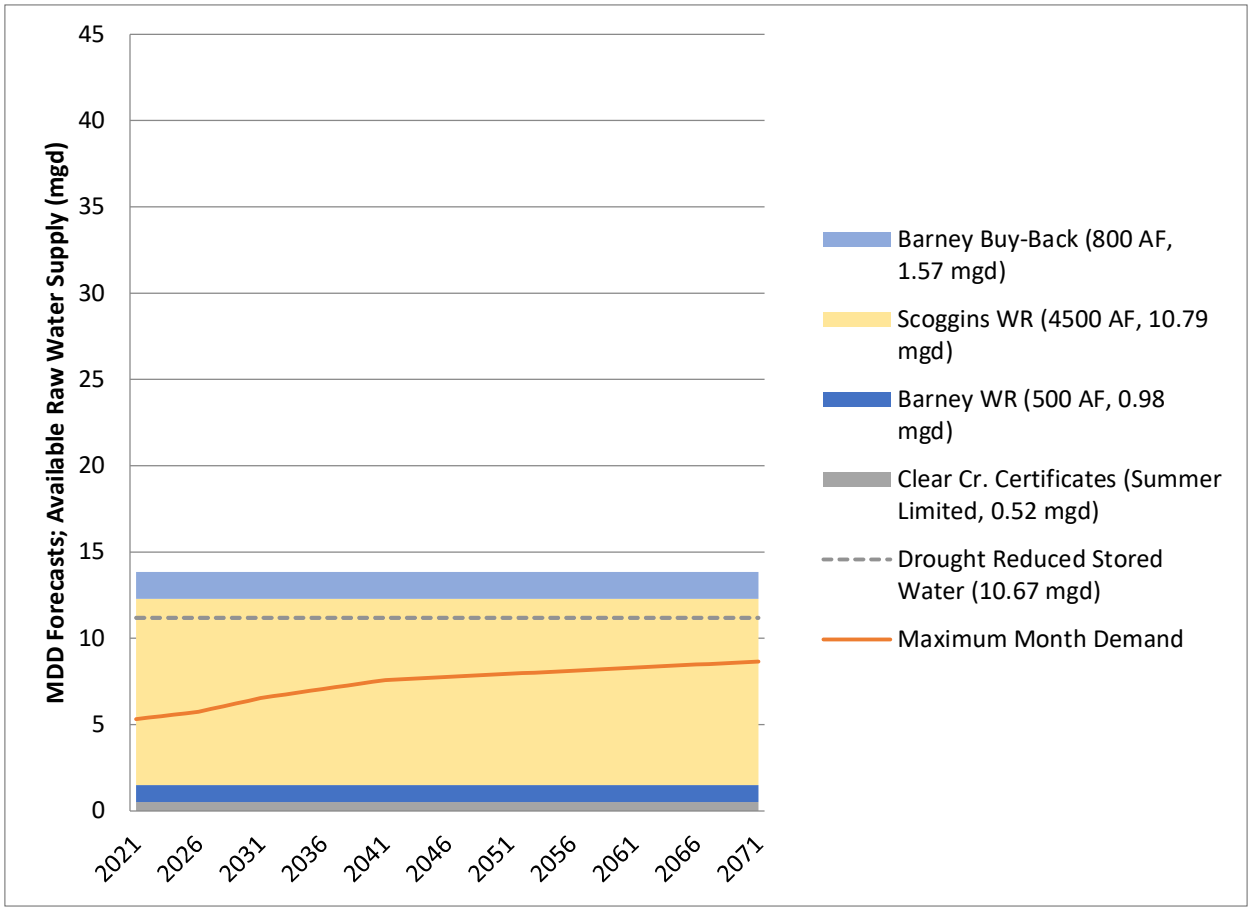


Note:

1. Stored water rights (Barney Buy-Back, Hagg Lake, and Barney Reservoir) have been converted from total stored volume to release rate assuming the full stored right, a 190 day release period, 1.5 maximum month release peaking factor, and loss/reduction factors listed in **Section 4.3.1.2**.

Figure 4-1 – If all water rights were accessible and available during the maximum demand month (typically August or July), the City would have over four times the necessary combined water rights from both in-stream and storage impoundment sources, treated by either the City or the JWC, to supply system demands beyond 2071. However, all water rights are not currently available when demands are greatest.

Figure 4-2 | Estimated Available Raw Water Supply during Peak Demands

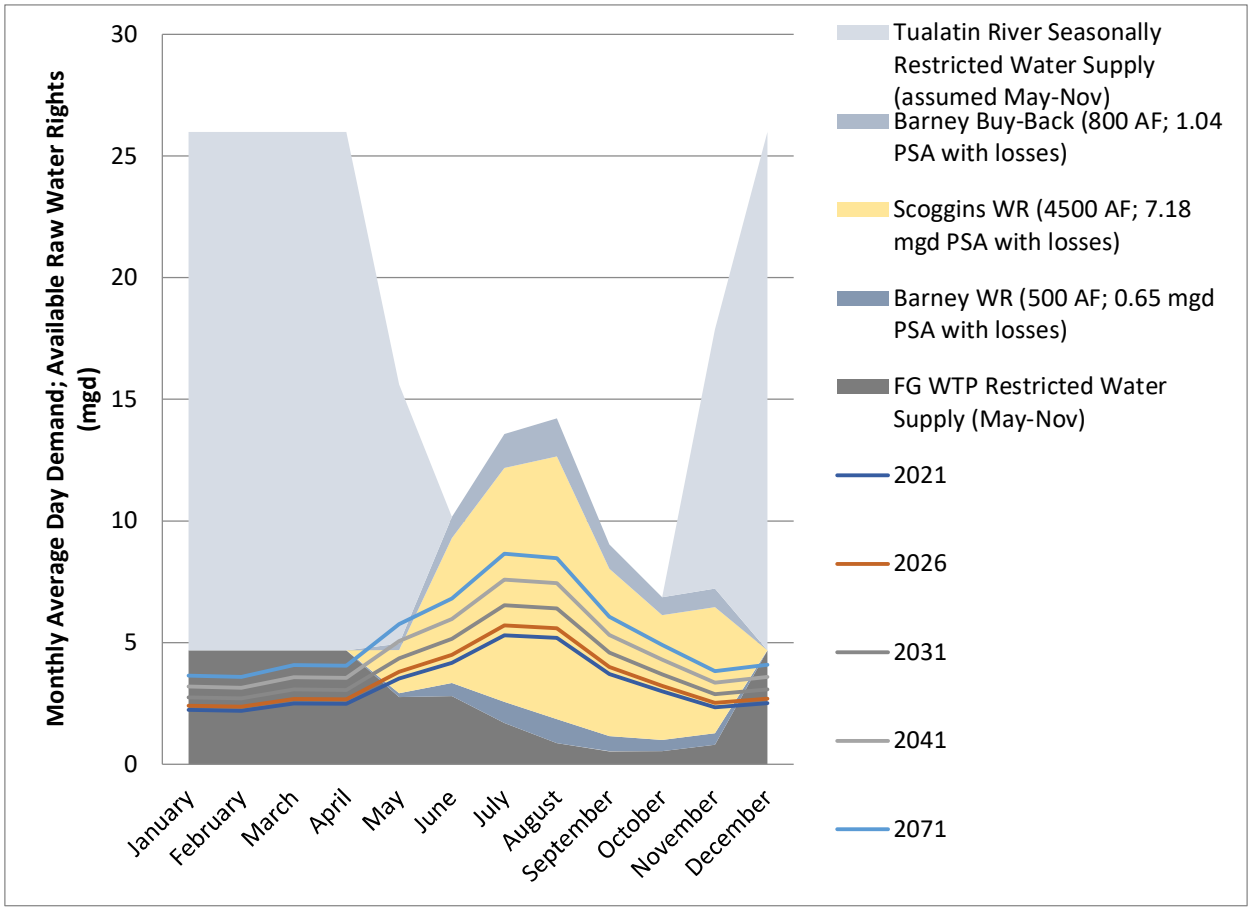


Note:

1. Only water rights that are not regulated off in the summer are shown (assumed 1917 Clear Creek Right and impoundment storage rights).
2. Available raw water from the Clear Creek Certificates is limited to WR 2194 at 0.52 mgd.
3. Impoundment release flow rates are calculated assuming the full stored right, a 190 day release period, 1.5 maximum month release peaking factor, and loss/reduction factors listed in Section 4.3.1.2
4. The drought reduced stored water volume shown (dashed line) is assumed to be 80 percent of the City's initial stored volume in both Hagg Lake and Barney Reservoirs. Clear Creek maintained at 0.52 mgd.

Figure 4-2 - Raw water supply is limited during peak summer season demands to only the 1917 Clear Creek water right supplied by the City, and stored impoundment rights supplied by the JWC. Assuming no drought restrictions, it is anticipated that the City has sufficient existing rights to meet summer season demands through 2071. If a 20 percent drought reduction is included to the stored water rights, the City still maintains sufficient raw water supply.

Figure 4-3 | Estimated Raw Water Availability, Regular Seasonal Limitations

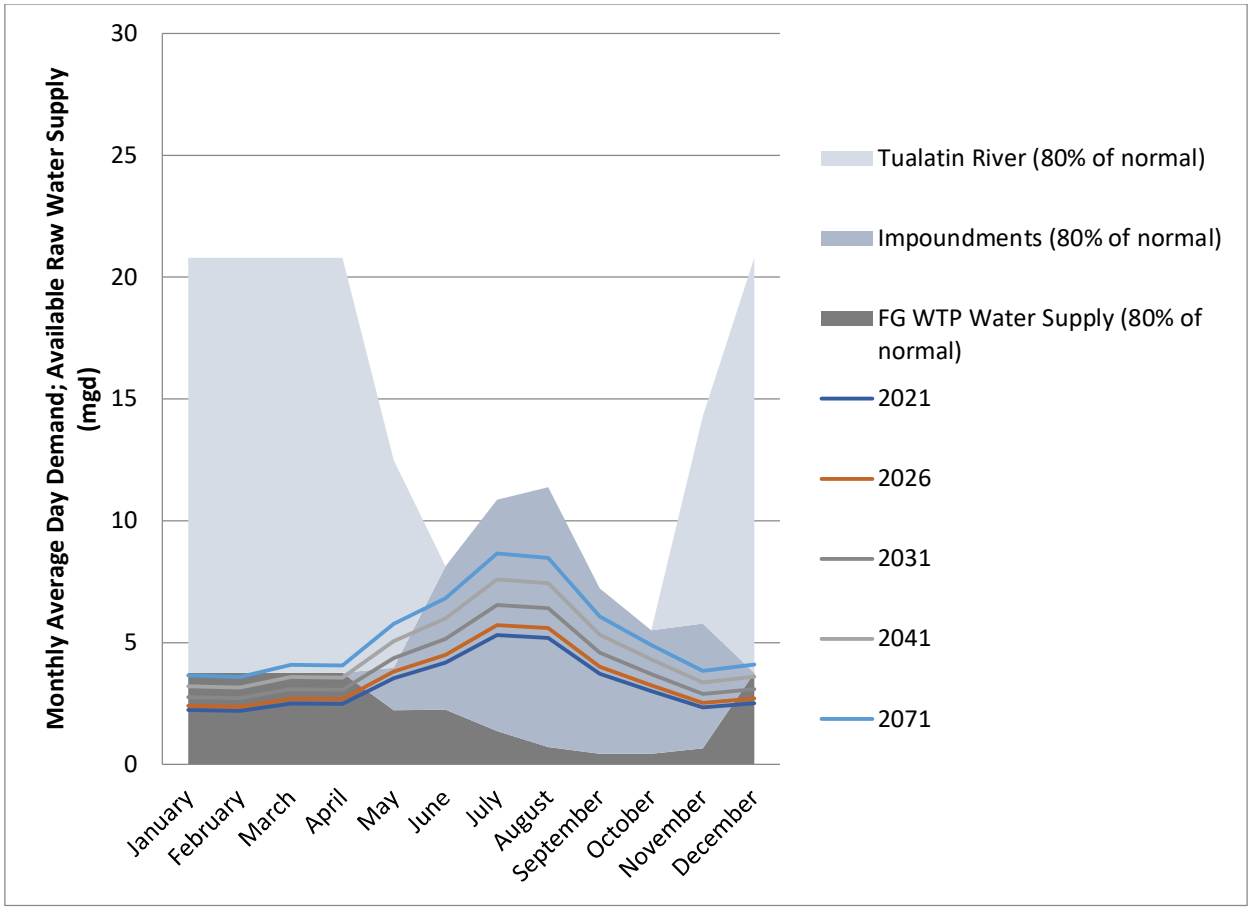


Note:

1. Raw water impoundment stored water rights (Barney, Hagg Lake) assume the full stored right, a 190 day release period, historical monthly peaking factors (**Table 4-3**), and loss/reduction factors listed in **Section 4.3.1.2**.
2. Raw water supply to the City WTP is represented by 2019 average flows for May through November.

Figure 4-3 –Historically, water right availability has been limited in the summer. If the City has full access to these assumed rights, adequate supply is available through 2071. The Tualatin River Right is assumed regulated off for May-November. The City's Clear Creek Rights are shown at historical takes for May – November, and the full treatment capacity of the WTP for the rest of the year. The impoundment storage shown is assumed 100 percent of the stored capacity, released from May-November (190 days), with loss/reduction factors and historical peaking factors applied.

Figure 4-4 | Estimated Raw Water Availability, Seasonal and 20% Drought Limitations



Note:

1. Although drought may not impact raw water supplies in non-summer months, drought was assumed throughout the year for a conservative estimate.
2. Under drought conditions, all raw water supplies are assumed to be reduced by 20 percent.
3. Drought impoundments include all potential water rights from Barney Reservoir and Hagg Lake, including the buy-back option capacity in Barney Reservoir. Supply assumes 80 percent total stored water capacity, a 190 day release period, historical monthly peaking factors (**Table 4-3**), and loss/reduction factors listed in **Section 4.3.1.2**

Figure 4-4 – Even under a 20 percent drought condition, the City maintains sufficient raw water rights throughout the year. See **Section 4.3.1.3** for additional discussion on drought limitations.

4.3.2 Hydraulic and Finished Water Capacity Analysis

4.3.2.1 WTP Supply Limitations

The City supply system and the JWC supply system are both limited by raw water availability, treatment capacity, and transmission capacity.

The City WTP supply is currently limited by:

- Raw water supply in the summer, as low as 0.52 mgd (Clear Creek Certificate 2194)
- Raw Water Transmission and treatment, maximum 3.7 mgd

The City's JWC supply is limited by:

- *Currently*–transmission capacity through the 24-inch JWC TL, approximately 6.1 mgd
- *Within 20 years*
    - Raw water availability in the summer under drought conditions, see **Figure 4-4**

4.3.2.2 North Plains Wholesale Demand

The JWC provides wholesale water to the City of North Plains through a long-term supply contract which includes supply capacity increases over time to account for growth in North Plains. The City is obligated to supply a portion of this wholesale need proportional to City owned capacity in the JWC WTP which is 10 mgd of the total 85 mgd WTP capacity, approximately 11.76 percent. **Table 4-4** presents the JWC's contractual wholesale supply to North Plains through 2035 and Forest Grove's portion of this. For this analysis, future supply beyond 2035 to North Plains was assumed to be constant at 0.29 mgd.

By 2035, Forest Grove will have 9.71 mgd available of the original 10 mgd capacity. North Plains is supplied off the 72-inch JWC NTL, not the 24-inch JWC TL, and so the full 6.1 mgd capacity of the 24-inch JWC TL is available to the City.

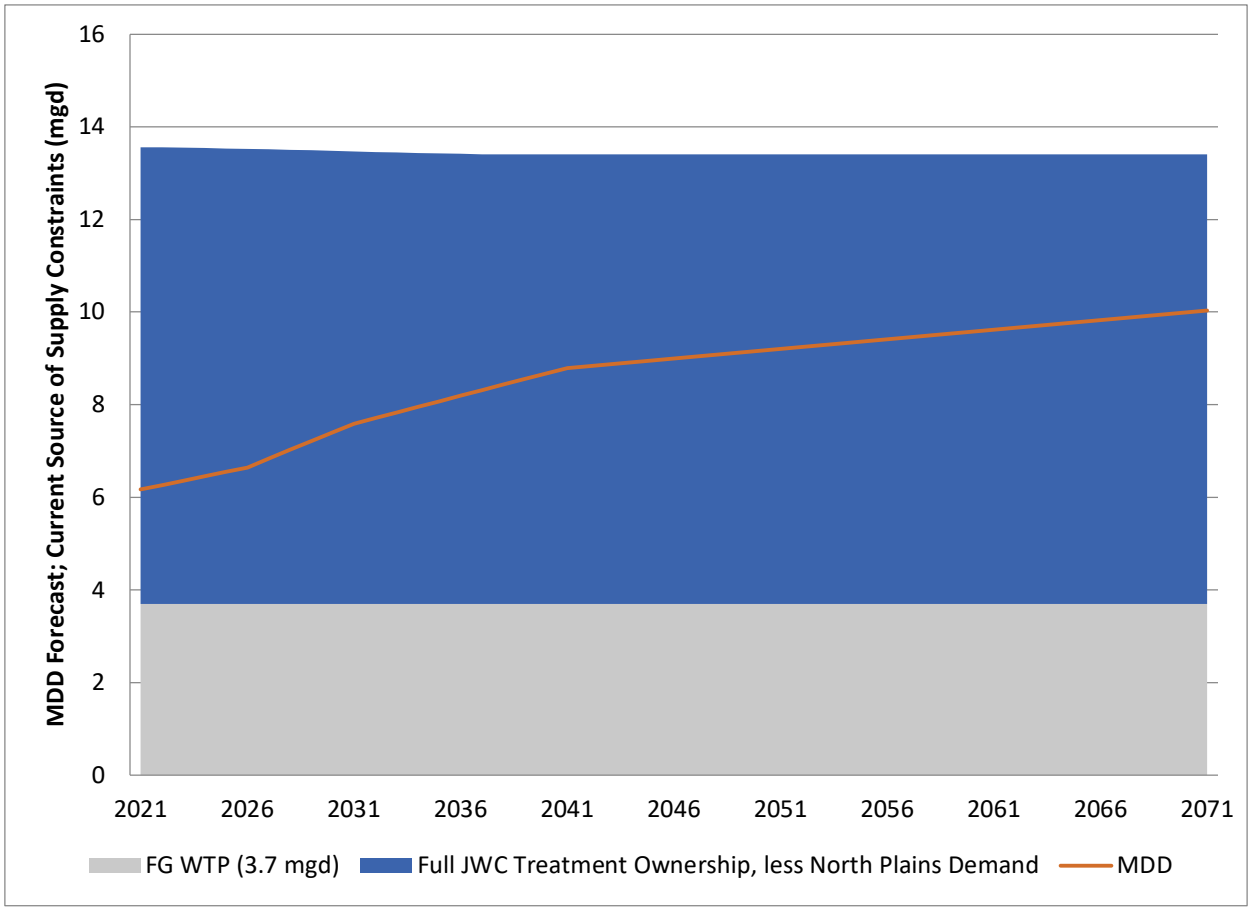
Table 4-4 | North Plains Wholesale Supply – Contracted Capacity

Year	JWC supply to North Plains (mgd)	Forest Grove portion (mgd)
2020	1.2	0.14
2025	1.5	0.18
2030	2.0	0.24
2035	2.5	0.29

4.3.2.3 Finished Water Capacity Findings

The City does not have sufficient available summer raw water rights or transmission capacity to utilize the full treatment capacity of either the City of JWC WTPs (**Figure 4-5** and **Figure 4-6**). City supply is most limited by the lack of water right availability other than the 1917 water right and JWC supply is most limited by the 24-inch JWC TL capacity. The most immediate finished water capacity need is additional transmission capacity in the 24-inch JWC TL within the next five years to serve MDD. This recommendation is addressed in the CIP section.

Figure 4-5 | Finished Water Supply Capacity: Treatment Limitations



Note:

1. JWC Supply Less North Plains calculation linearly interpolated between years listed in **Table 4-4.**

Figure 4-5 – Assuming the City has access to the full treatment capacity/ownership at the JWC and City WTPs, no additional treatment capacity is required through 50 years.

Figure 4-6 | Finished Water Supply Capacity: Treatment, Transmission, and Raw Water Supply Limitations

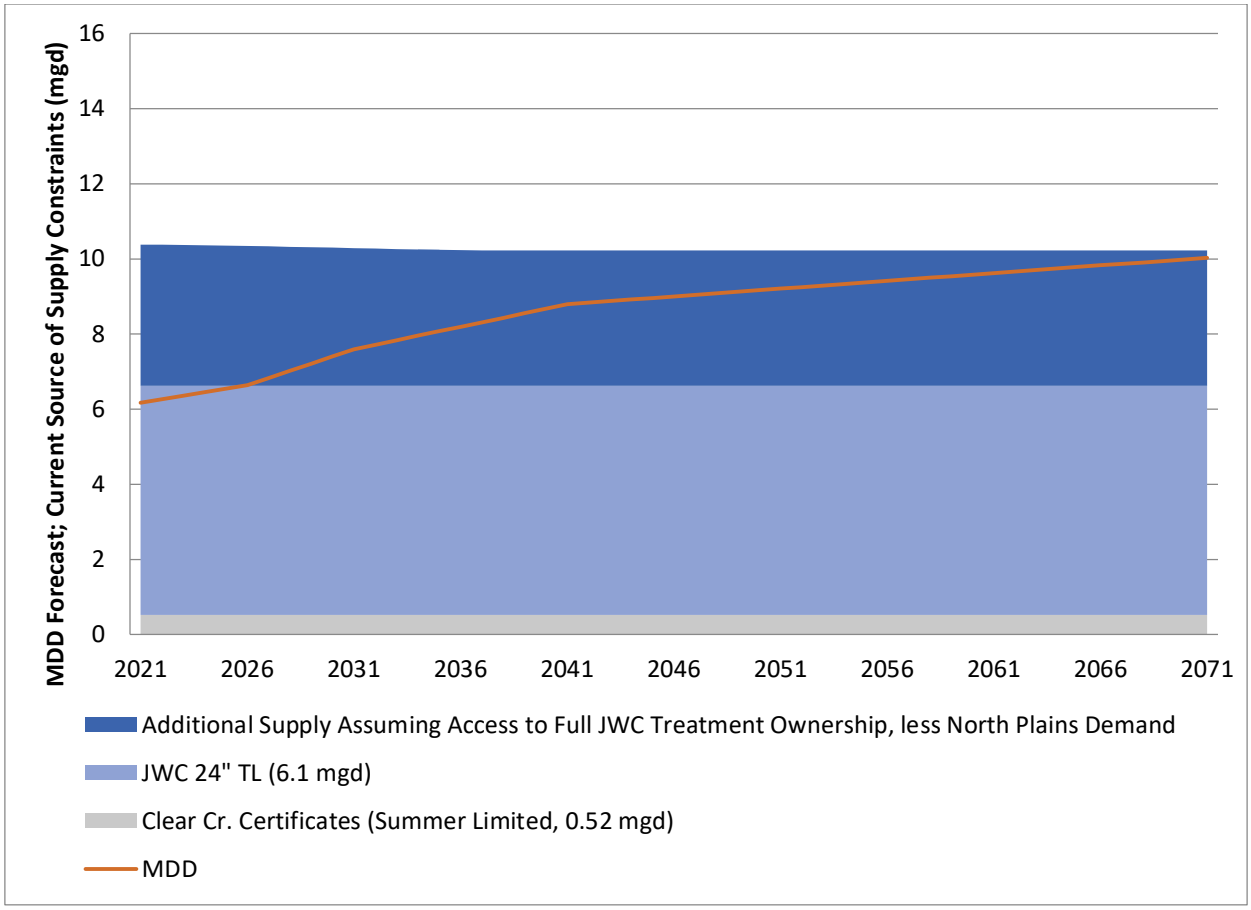


Figure 4-6 – The City does not have sufficient available summer rights or transmission capacity to utilize the full treatment capacity of either the City WTP or the JWC WTP. City supply is limited to the 1917 water right, and JWC supply is most limited by the 24-inch JWC TL capacity. With current agreements, the City will need additional capacity within the next five years to meet MDD. If the full JWC treatment right could be accessed, the City would have sufficient capacity through 50 years, assuming no additional North Plains supply.

4.4 Supply Strategy

The most pressing supply need for the City is increased transmission from the JWC to the 10th Ave Control Station. The City should evaluate transmission options in conjunction with seismic resilience evaluations as recommended by the SRP and continued coordination with the City of Hillsboro.

While there is not a near term need to develop additional source of supply, the City should begin planning to complete a separate Water Supply Study to address supply deficiencies. An initial review based on City public works and engineering staff observations of the City's existing

infrastructure was documented and is included in Appendix E. The following sections document several alternatives, but significant key information is missing to make an informed decision. The next steps documented in Section 4.4.4 should be completed to address the knowledge gaps and select an alternative to meet supply.

4.4.1 Supply Scenarios

Five supply scenarios were explored to accommodate existing and projected future City water demands. Supply scenarios considered are briefly described in the following list and summarized in Table 4-5. Supply scenarios are illustrated in Figure 4-7 through Figure 4-11 at the end of this section. Plate 1 in Appendix A is available for reference of the existing system.

1. Base Scenario - Maintain existing supply system and construct emergency Heather Street Intertie on 72-inch JWC NTL

2. Decommission existing City WTP, replace and expand 5 MG Reservoir, improve existing JWC connection, construct emergency Heather Street Intertie, and add a second POD for the Clear Creek watershed water rights at the JWC Springhill Pump Station intake facility

3. Decommission existing City WTP, replace 5 MG Reservoir, add a second point of diversion for the Clear Creek watershed water rights at the JWC Springhill Pump Station intake facility, and construct Heather Street Intertie for both normal and emergency supply, construct new storage tank and booster pump near Heather St Intertie

4. Maintain existing City WTP, replace and expand 5 MG Reservoir, improve existing JWC connection, and construct emergency Heather Street Intertie

5. Maintain existing City WTP, replace and expand 5 MG Reservoir, improve existing JWC connection, construct emergency Heather Street Intertie, construct connection from Tualatin Valley Irrigation District (TVID) supply line to City WTP to increase raw water supply

Table 4-5 | Supply Scenarios

Facilities	Scenarios				
	1	2	3	4	5
Rehab City WTP and Raw Water Supply	X			X	X
Decommission City WTP and Raw Water Supply		X	X		
Continue JWC participation and investment	X	X	X	X	X
Improve Existing 24-inch JWC TL to 10th Ave		X		X	X
Improvements to 10th Ave Control Facility	X	X	X	X	X
Construct Heather St Emergency Intertie	X	X	X	X	X
Construct Heather St Supply Intertie			X		
Replace 5 MG Reservoir with Like Reservoir	X		X		
Replace and expand 5 MG Reservoir onsite		X		X	X
New Reservoir and Pump Station at Heather St Intertie			X		
Connect to TVID					X

4.4.2 Facility Investments

The following sections discuss the implications for selecting each of the supply facility options listed in Table 4-5. Some data such as required infrastructure improvements and cost, seismic resilience, or capacity available for lease requires further study or coordination with other water utilities which is beyond the scope of this Plan. It is recommended the City acquire this additional information to make a fully informed decision on long-term supply strategy. This additional required information is summarized by supply scenario in Section 4.4.3.

Unless noted otherwise, seismic improvements listed in the following sections are summarized from the City's *Seismic Resiliency Plan (SRP)* prepared by InfraTerra, Inc. As of the writing of this master plan, the SRP is in draft final format and will be finalized with the completion of the master plan. The bulk of the work for the SRP was completed in September 2020. The SRP did not address improvements required at JWC facilities. Additional structural or geotechnical investigations may be required for specific JWC or City facilities. Section 6 of this master plan presents a full summary of the SRP findings.

4.4.2.1 Rehab City WTP and Raw Water Supply

The City's WTP and raw water supply is aging, with some facility components over 100 years old, and could likely benefit from rehabilitation, replacement, and facility improvement. Maintaining these facilities would allow the City to retain local control over some supply and provide source redundancy to the City's connection to the 24-inch JWC TL. However, the City's WTP is only a three-season finished water supply due to raw water supply limits during the summer. Currently, summer finished water supply is reduced to approximately 0.52 mgd.

Per the SRP, the City's WTP meets the SRP's Immediate Occupancy performance criteria and is expected to survive the CSZE. The SRP also states that some structural and non-structural damage

is possible at the WTP, but it is unlikely that such damage will result in significant disruption of plant operation. Per the SRP, the RWTM is vulnerable to significant damage from a CSZE due to areas of liquefiable soil and a potentially vulnerable creek crossing at the Stringtown Road Bridge. The SRP recommends replacing the RWTM with earthquake resistant pipe and/or doing additional geotechnical analysis to narrow the areas where seismic geohazards indicate more seismically resilient pipe is needed. The SRP indicates the City's 5 MG Reservoir, which serves as the chlorine contact basin for the WTP, is vulnerable to structural damage in a CSZE which could result in the loss of some or all the stored water. It was also noted that the slope below the 5 MG Reservoir may deform, leading to damage to the 20-inch diameter distribution main which provides finished water to the 368 pressure zone as well as finished water supply to the David Hill and Watercrest pump stations.

A comprehensive facility plan for the City WTP is recommended to assess operational limitations and address age and condition issues identified by City staff, including:

- *WTP Transfer pumps* – City staff observed the transfer pumps, which pump water from the sedimentation basin up to the WTP filters, seem to have shortened motor lives and require repairs more frequently than expected. The pumps are not covered or in a building and operational issues may be due to exposure to the elements.

- *WTP Sedimentation basin* - constructed in 1912, the sedimentation basin is the oldest facility on the WTP site. This reinforced concrete structure has exceeded its expected useful life.

- *WTP Dewatering and solids handling* - the existing dewatering process requires the addition of perlite which increases cost. The dewatering equipment is currently housed inside the WTP shop making the space unusable for other City operations and maintenance needs. The location of the dewatering equipment in the shop may also indicate a lack of appropriate storage on the WTP site.

- *Raw Water Pumps -* The raw water booster pump station, located in an underground vault adjacent to Gales Creek Road, was connected to the raw water transmission main in 1979 and is used to increase flows to the WTP from the gravity RWTM flow of 2.7 mgd to 3.7 mgd to accommodate higher system demands. The remaining lifespan for this facility is unknown.

- *16-inch Raw Water Transmission Main to City WTP -* Clear Creek watershed source water is conveyed to the WTP via a 7.8 mile 16-inch CCP RWTM. The RWTM serves as the sole pipeline for raw water supply to the City's WTP. City staff have observed cracking in the exterior mortar coating. Water industry research indicates that cracks in the coating is the most common cause CCP failure. A portion of the RWTM was also constructed in a known landslide area between the Clear Creek crossing and Soda Springs Road. The SRP recommends that over half the RWTM be replaced due to seismic risk and additional geotechnical work be done to maintain the pipeline (see Section 6 for additional SRP discussion). Due to the location of the RWTM and the current condition, it is considered

vulnerable to damage from a potential landslide or CSZE. Loss of the RWTM will result in the loss of raw water supply to the WTP.

4.4.2.2 Decommission City WTP

City staff have identified operational challenges and facility condition issues due to age and construction at the existing WTP and RWTM. The WTP has inadequate capacity to independently meet the forecasted ADD within 10 years. Seasonal limitations on the Clear Creek watershed source also mean the City's WTP finished water supply is at its lowest annual capacity during the highest annual system demand. The City WTP currently meets less than one tenth of MDD during in-stream raw water supply restrictions.

Decommissioning the WTP would reduce the capital expenditures necessary to improve operational performance and to mitigate seismic vulnerability which might be required to prevent a loss of the finished water supply from the WTP. However, decommissioning the City WTP would make the JWC the City's only finished water supply and increase dependence on the capacity-limited 24-inch JWC TL.

4.4.2.3 Continue JWC Participation and Investment

Under all scenarios, the City should continue to participate and invest in the JWC supply infrastructure. The City is reliant on the JWC Fern Hill Reservoirs for both system storage and significant supply, particularly in the summer months. According to the *2018 JWC WTP Facility Plan*, the existing JWC WTP is not anticipated to withstand a CSZE. Investment in retrofitting or replacing existing JWC WTP facilities is anticipated with the timing of improvements to be determined by the JWC partners.

4.4.2.4 Improve Existing JWC Transmission to 10th Avenue Control Station

Currently, the City receives JWC finished water supply through a single 24-inch JWC TL jointly owned with the City of Hillsboro. As stated in the *2010 Water Master Plan*, The City's 50 percent share of capacity in this transmission line is limited to 6.1 mgd, rather than the 10 mgd City treatment ownership in the JWC WTP. This 6.1 mgd is not sufficient to meet projected future summer demand and the JWC is the City's primary finished water supply during summer months. Several alternatives were discussed to increase finished water supply from the JWC to the 10th Avenue Control Station:

- *Replace and upsize transmission main* - The existing 24-inch JWC TL could be replaced with a larger pipe. Per the SRP, the existing transmission main is vulnerable to damage in a CSZE. A replacement main would be built for seismic resilience as well as increased capacity. This would likely mean the existing transmission main would be out of service during construction and the City would need to rely on the City WTP which does not have adequate capacity to meet summer demands. This alternative would be costly and Hillsboro may not want to invest in additional capacity they do not need, leaving a larger share of the pipe replacement cost to the City.

- *Parallel transmission main* - A parallel, seismically resilient transmission main could be built to increase capacity. This would allow for the existing 24-inch JWC TL to remain in service during construction and would also address seismic resilience.

- *Lease capacity from Hillsboro* – The City of Hillsboro uses their share of the existing 24-inch JWC TL to serve a small number of customers in the Cherry Grove area. Hillsboro may have capacity available in the 24-inch JWC TL which they would be willing to lease to the City. Depending on Hillsboro's future finished water supply needs, leasing capacity may not be a long-term solution for the City. Although this alternative is the lowest cost it does not address seismic vulnerability of the existing 24-inch JWC TL.

If the JWC becomes the sole finished water supply for the City, there is no existing redundant JWC pipeline that connects to the City water system, or an alternate source of finished water should the 24-inch JWC TL fail or be taken out of service. The *2010 Water Master Plan* identifies a parallel transmission line as a recommended system improvement which would enable the City to receive the full JWC capacity under normal operating conditions. This project is included in the CIP, separate from the Water Supply Study. Completion of this project may adjust impacts and costs of other facility improvements discussed in this section.

4.4.2.5 Improve 10th Avenue Control Facility

The 10th Avenue Control Station houses the control valves from the 24-inch JWC TL to City distribution mains. An 18-inch Cla-Val pressure and flow control valve was replaced with parallel 8 and 16-inch Singer pressure and flow control valves in 2020. These control valves are currently operated as PRVs.

Per the SRP, the soil around the 10th Avenue Control Station is susceptible to liquefaction and pipe failure is possible where the pipes pass through the floor and walls of the station with rigid connections. In addition, the SRP recommends a detailed structural evaluation to determine if the Control Station building meets Immediate Occupancy performance criteria and what improvements may be required.

4.4.2.6 Construct Heather Street Intertie – Emergency

Hillsboro, TVWD, and Beaverton jointly own and operate the 72-inch JWC NTL that extends along the eastern city limits and currently provides JWC partners Hillsboro and TVWD with finished water. An existing 16-inch tee and blind flange located near the intersection of Mountain View Lane and Heather Street could serve as a future City connection point to the 72-inch JWC NTL and provide emergency redundancy with the existing 24-inch JWC TL connection to the 10th Avenue Control Station, should the 10th Avenue Control Station or the 24-inch JWC TL fail. The City is currently designing an emergency intertie connection, the Heather Street Intertie, to the 72-inch JWC NTL at this location.

As an emergency connection, this intertie is only anticipated to operate under extreme conditions such as a fire flow event. While emergency finished water supply is available, the potential for

long-term leasing of finished water supply capacity in the 72-inch JWC NTL from JWC is still unknown.

Distribution system improvements will be needed to provide higher flows from the proposed intertie without over-pressurizing customers near the intertie. Recommended improvements depend on the ultimate design flows selected by the City but upsizing to 20-inch diameter transmission is proposed. Distribution limitations and improvement options are discussed in more detail in Section 5.

4.4.2.7 Construct Heather Street Intertie – Supply

As discussed in the prior emergency Heather Street Intertie section, an emergency only connection is currently being designed for finished water supply from the 72-inch JWC NTL. This connection could be expanded to a regular finished water supply intertie, much like the 10th Avenue Control Station. This would provide redundancy to 10th Avenue and the 24-inch JWC TL. It would not provide a fully redundant finished water supply like the City's WTP because both the 72-inch JWC NTL and the 24-inch JWC TL receive water from the JWC WTP and Fern Hill Reservoirs.

The City does not currently own capacity in the 72-inch JWC NTL and would be required to lease or purchase available capacity to use the intertie as a regular finished water supply. Hillsboro and TVWD are currently partnering in the development of a second regional source, the Willamette Water Supply Program. With this new supply available in 2026 leasing capacity may become available in the 72-inch JWC NTL at least for the near-term future until Hillsboro and TVWD system demands increase to the point where both Willamette and 72-inch JWC NTL full capacities are needed.

Distribution system improvements will be needed to provide higher flows from the proposed intertie without over-pressurizing customers near the intertie. Recommended improvements depend on the ultimate design flows selected by the City but upsizing to 20-inch diameter transmission is proposed. Distribution limitations and improvement options are discussed in more detail in Section 5.

4.4.2.8 Replace 5 MG Reservoir

The 5 MG Reservoir was constructed in 1948 and is a buried reinforced concrete structure divided in to two 2.5 MG cells for operational flexibility. Per the SRP, the 5 MG Reservoir is vulnerable to structural damage in a CSZE and the fill slopes below the tank are susceptible to deformation under high ground water conditions.

The reservoir is a critical facility for the City water system, supplying service pressure to the 368 Zone which serves most City customers and providing suction supply to the Watercrest and David Hill Pump Stations which fill the David Hill Reservoir. City staff have observed voids in the sidewalls and floor of the existing 5 MG reservoir from the original construction where wooden concrete forms have deteriorated. As these forms continue to degrade, the voids may be an on-going source of minor leaks in the reservoir. A more substantial leak was identified by City staff in 2018

northwest of the discharge sump, in the floor of the reservoir on the north side. The concrete was patched to seal the leak.

Replacing the 5 MG Reservoir with a seismically resilient similar volume tank would address condition and seismic issues with the existing tank. Additionally, replacing only the existing volume would allow for a smaller footprint, which may be amenable to the site slope. However, this would mean additional storage required to address future storage deficiencies in the 368 Zone would need to be placed elsewhere.

4.4.2.9 Replace and Expand 5 MG Reservoir Onsite

As discussed in the prior section, the 5 MG Reservoir is a critical facility and needs to be replaced due to age, condition, seismic vulnerability, and projected capacity issues. As presented in Section 5 the existing 5 MG Reservoir has inadequate capacity to meet finished water storage. One option for reservoir replacement is to expand the 5 MG Reservoir at the existing site. A preliminary tank siting by City staff indicates that two cylindrical 5 MG prestressed concrete tanks may fit on the existing site. The existing 5 MG Reservoir would have to be demolished and replaced in phases, one cell at a time, to use the existing site, to allow the City WTP to continue receiving adequate chlorine contact time, and to provide 368 Zone system pressure during construction.

4.4.2.10 New Reservoir and Pump Station at Heather Intertie

To complement a new finished water supply intertie with the 72-inch JWC NTL and to offset 368 Zone storage deficiencies (see Section 5), the City could construct a ground-level storage reservoir and booster pump station near the Heather Street Intertie. The storage reservoir and pump station capacity would mitigate future 368 Zone storage deficiencies in lieu of expanding the 5 MG Reservoir. Locating this ground-level reservoir and pump station near the 72-inch JWC NTL intertie would also help to mitigate industrial fire flow deficiencies in the distribution system near the intertie. The ground-level reservoir would not be able to supply customers by gravity and the pump station would be vulnerable to power outages or require back-up power.

4.4.2.11 Connect to TVID

The TVID receives raw water from the Tualatin River and storage impoundments through the JWC's Springhill Pump Station, a 33-inch diameter raw water transmission main which travels through the City. The City has proposed leasing capacity in the TVID raw water transmission line to access the City's in-stream and stored water rights in the Tualatin River system. This proposed raw water supply essentially transfers the raw water supply that would have been treated at the JWC WTP to the City' WTP and at the same time does not increase the total raw water supply available to the City. Instead, it would allow expanded operation of the City's WTP which would increase the City's overall treatment capacity in the summer when in-stream flows in Clear and Roaring Creeks are low, without needing to expand the City's treatment ownership in the JWC WTP. The capacity available for lease in the TVID transmission main is unknown and total supply benefit would continue to be limited by the City WTP capacity of 3.7 mgd.

To transmit water from TVID's transmission main near NW Thatcher Road and NW David Hill Road to the City's WTP, the City would need to construct and maintain a minimum of 3,000 feet of new, seismically resilient transmission main.

This alternative currently has several uncertainties including:

- unknown capacity available for lease in the TVID transmission main, particularly during summer months when irrigation use is highest
- unknown seismic resilience and required maintenance of the TVID transmission main
- potential issues with water rights

4.4.3 Scenario Benefits, Challenges, and Information Gaps

While many of the facilities described in the preceding section are shared between multiple supply scenarios, each scenario presents a unique set of benefits and challenges. Additionally, the City does not currently have access to some information such as expected performance during a seismic event or cost of improvements which will impact scenario selection. Table 4-6 summarizes the benefits, anticipated challenges, and additional information required to make an informed decision for each of the five supply scenarios.

4.4.4 City Next Steps

The City should complete a Water Supply Study to make an informed decision on the best long-term supply strategy and fill the remaining information gaps. The following actions are recommended as part of the Water Supply Study.

- Document and estimate costs for City WTP age and condition replacements.
- Document and estimate costs for City WTP and RWTM seismic improvements.
- Document and estimate costs for JWC seismic improvements for the JWC WTP, Fern Hill Reservoirs, and 24-inch JWC TL.
- Continue discussions on lease capabilities in the 72-inch JWC NTL and the 24-inch JWC TL with the City of Hillsboro.
- Discuss lease capabilities in the TVID transmission main with TVID.
- Investigate water rights requirements for TVID transmission.
- Perform a formal cost-benefit analysis of the supply scenarios.

- Investigate options to expand long-term raw water supply including groundwater, reducing raw water supply need through leasing finished water capacity from JWC partners, and participating in JWC planning and conservation efforts.

Table 4-6 | Scenario Benefits, Challenges, and Information Gaps

Scenario	Benefits	Challenges	Information Gaps
1 – Base Maintain Existing	▪ Known O&M ▪ Local supply control	▪ Does not address finished water storage deficit ▪ RWTM and 5 MG Reservoir seismically vulnerable	▪ City WTP required seismic improvements, age, and condition replacements
2 – JWC only Expand 5MG storage	▪ Consolidate future investment ▪ Simplify system ▪ Address storage deficit	▪ Reliant on a single source (JWC) ▪ Transmission through City distribution creates overpressure	▪ Lease capabilities in 72-inch JWC NTL & from the City of Hillsboro in the 24-inch JWC TL
3 – JWC only New Ground Reservoir	▪ Consolidate future investment ▪ Simplify system ▪ Storage adjacent to JWC supply point	▪ Pumped service to 368 Zone o energy cost o mechanical vulnerability o maintenance cost	▪ Siting and cost of reservoir and pump station ▪ Lease capabilities in 72-inch JWC NTL
4 – City WTP & JWC Expand storage	▪ Maintain 2 supply sources ▪ Local supply control ▪ Address storage deficit	▪ RWTM and 5 MG Reservoir seismically vulnerable ▪ Significant investment in seismic retrofitting and condition upgrades for both City WTP and JWC supplies	▪ Lease capabilities in 72-inch JWC NTL & from the City of Hillsboro in the 24-inch JWC TL ▪ City WTP seismic improvements, age, and condition replacements
5 – TVID Raw Water Supply to City WTP & JWC Expand storage	▪ Maintain 2 supply sources ▪ Local supply control ▪ Address storage deficit ▪ Continue to use Clear Creek watershed rights	▪ Significant investment in seismic retrofitting and condition upgrades for both City WTP and JWC supplies ▪ Investment in TVID transmission, including seismic evaluation and retrofitting	▪ Lease capabilities in TVID transmission ▪ City WTP seismic improvements, age, and condition replacements ▪ Water right requirements

Supply Scenario 1

Notes
1. City distribution system includes the David Hill Reservoir, the Watercrest & David Hill Pump Stations, PRV's, and distribution piping.
2. Future upper level distribution and storage facilities not shown
3. Not all JWC infrastructure shown

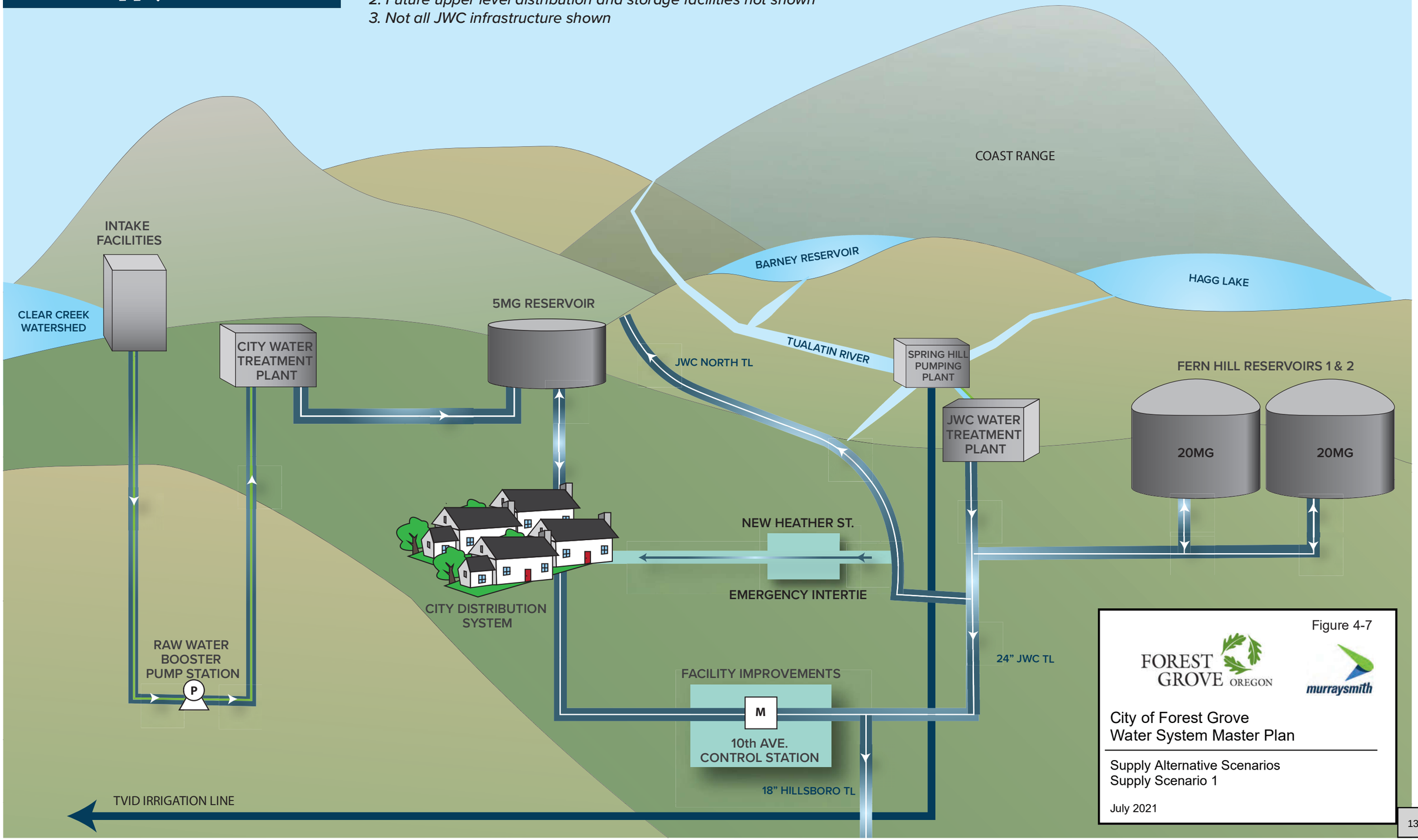


Figure 4-7

FOREST GROVE OREGON

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City of Forest Grove
Water System Master Plan

Supply Alternative Scenarios
Supply Scenario 1

July 2021

Supply Scenario 2

Notes
1. City distribution system includes the David Hill Reservoir, the Watercrest & David Hill Pump Stations, PRV's, and distribution piping.
2. Future upper level distribution and storage facilities not shown
3. Not all JWC infrastructure shown

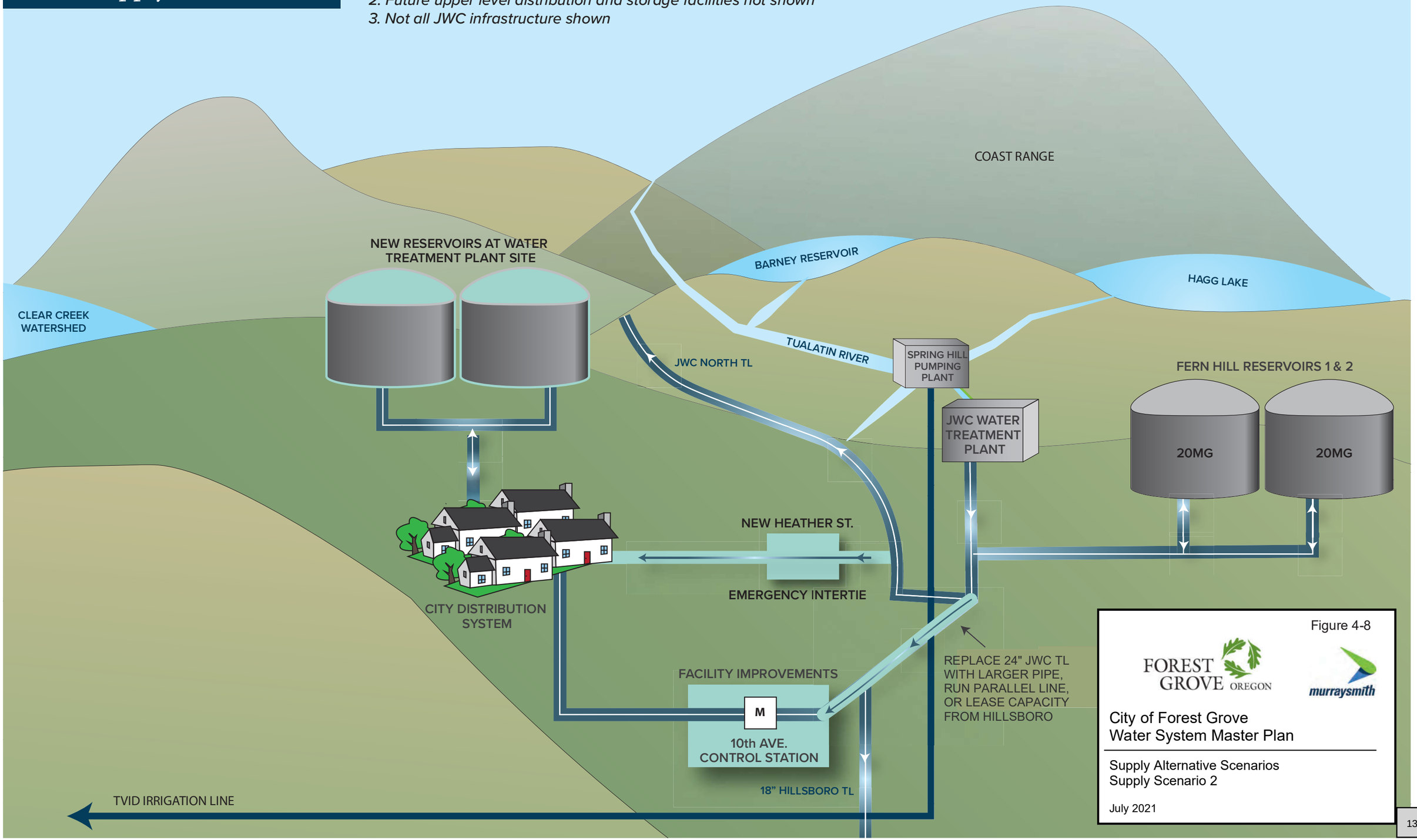


Figure 4-8

FOREST GROVE OREGON

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City of Forest Grove
Water System Master Plan

Supply Alternative Scenarios
Supply Scenario 2

July 2021

Supply Scenario 3

Notes
1. City distribution system includes the David Hill Reservoir, the Watercrest & David Hill Pump Stations, PRV's, and distribution piping.
2. Future upper level distribution and storage facilities not shown
3. Not all JWC infrastructure shown

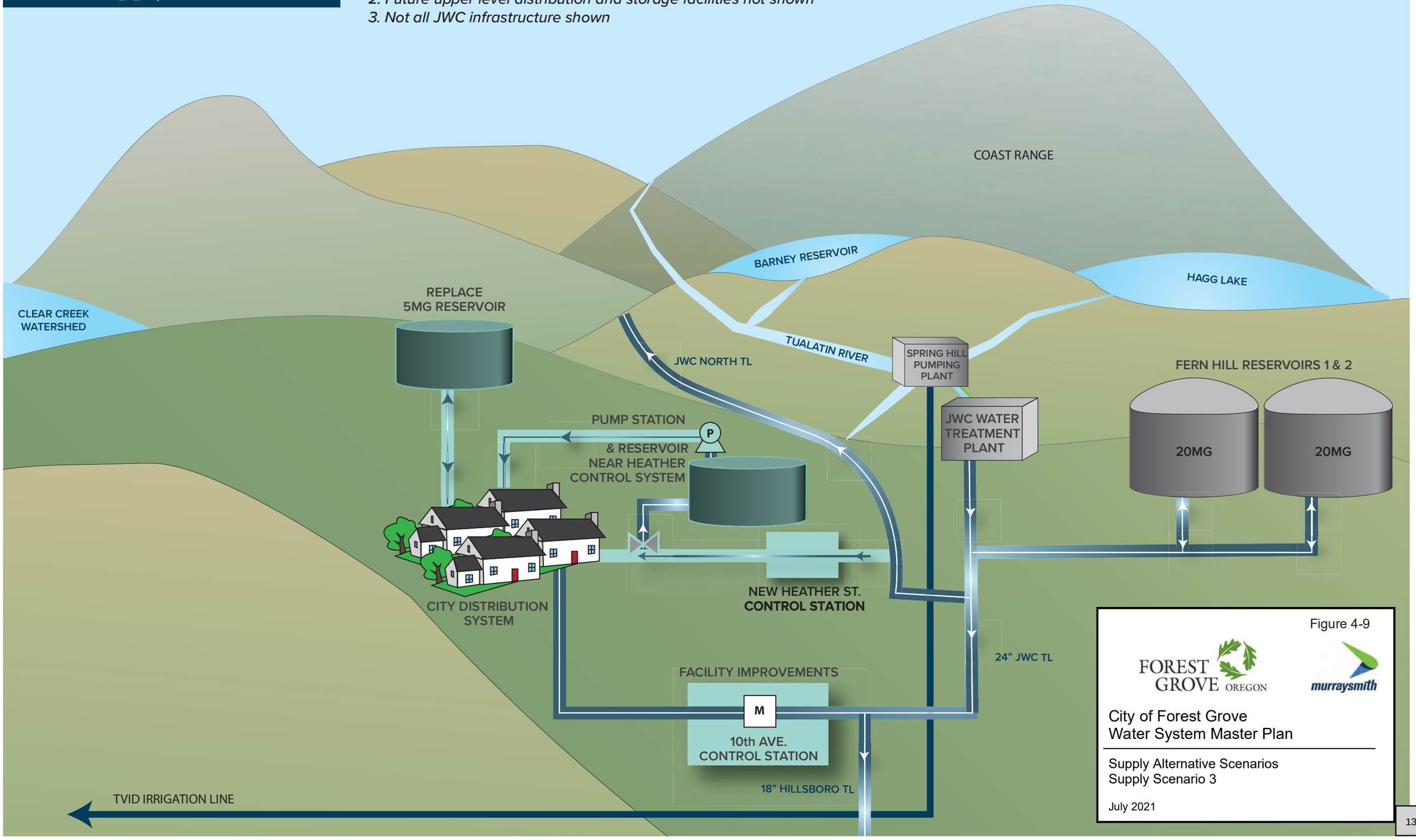


Figure 4-9

FOREST GROVE OREGON

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City of Forest Grove
Water System Master Plan

Supply Alternative Scenarios
Supply Scenario 3

July 2021

Supply Scenario 4

Notes
1. City distribution system includes the David Hill Reservoir, the Watercrest & David Hill Pump Stations, PRV's, and distribution piping.
2. Future upper level distribution and storage facilities not shown
3. Not all JWC infrastructure shown

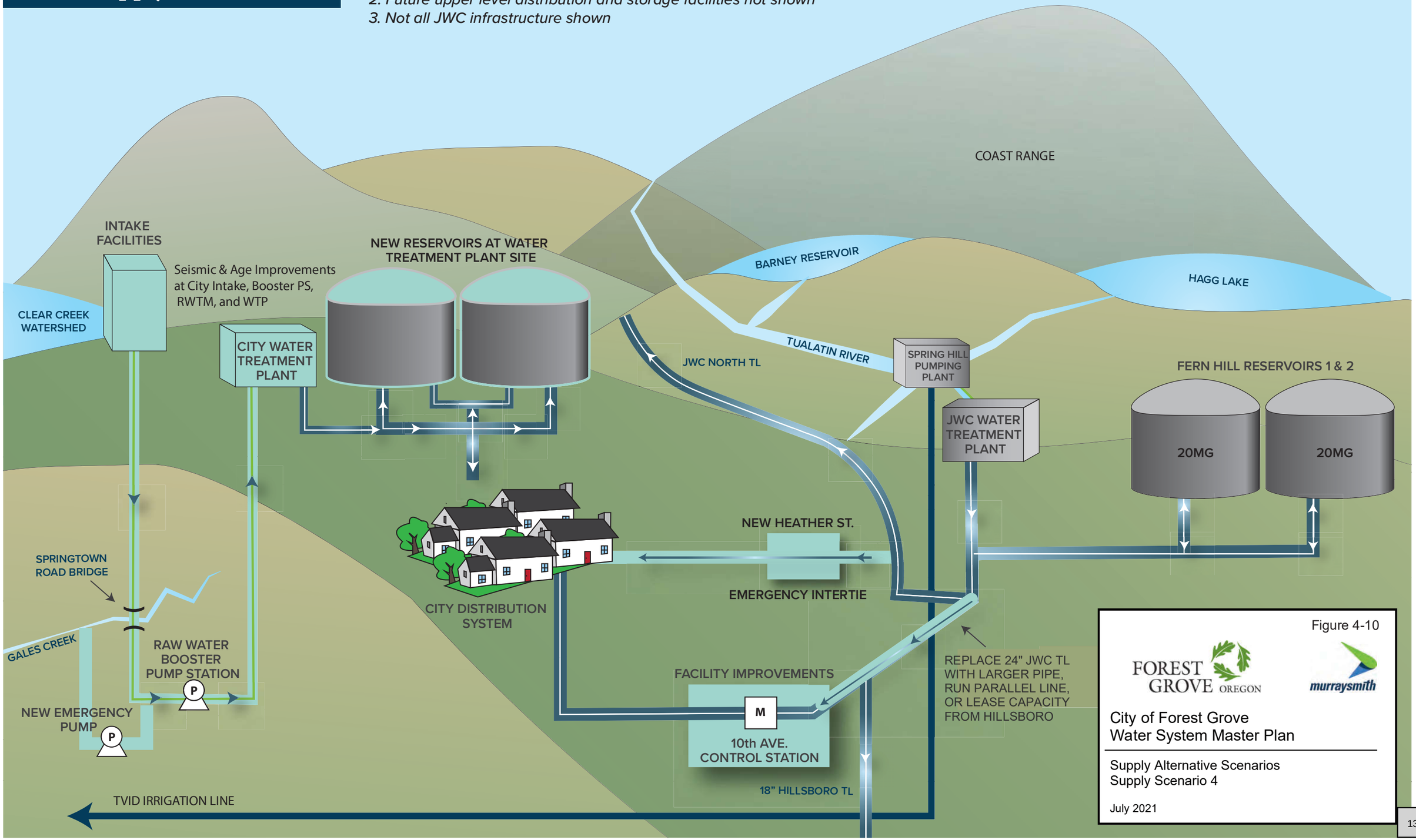


Figure 4-10

FOREST GROVE OREGON

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City of Forest Grove
Water System Master Plan

Supply Alternative Scenarios
Supply Scenario 4

July 2021

Supply Scenario 5

Notes
1. City distribution system includes the David Hill Reservoir, the Watercrest & David Hill Pump Stations, PRV's, and distribution piping.
2. Future upper level distribution and storage facilities not shown
3. Not all JWC infrastructure shown

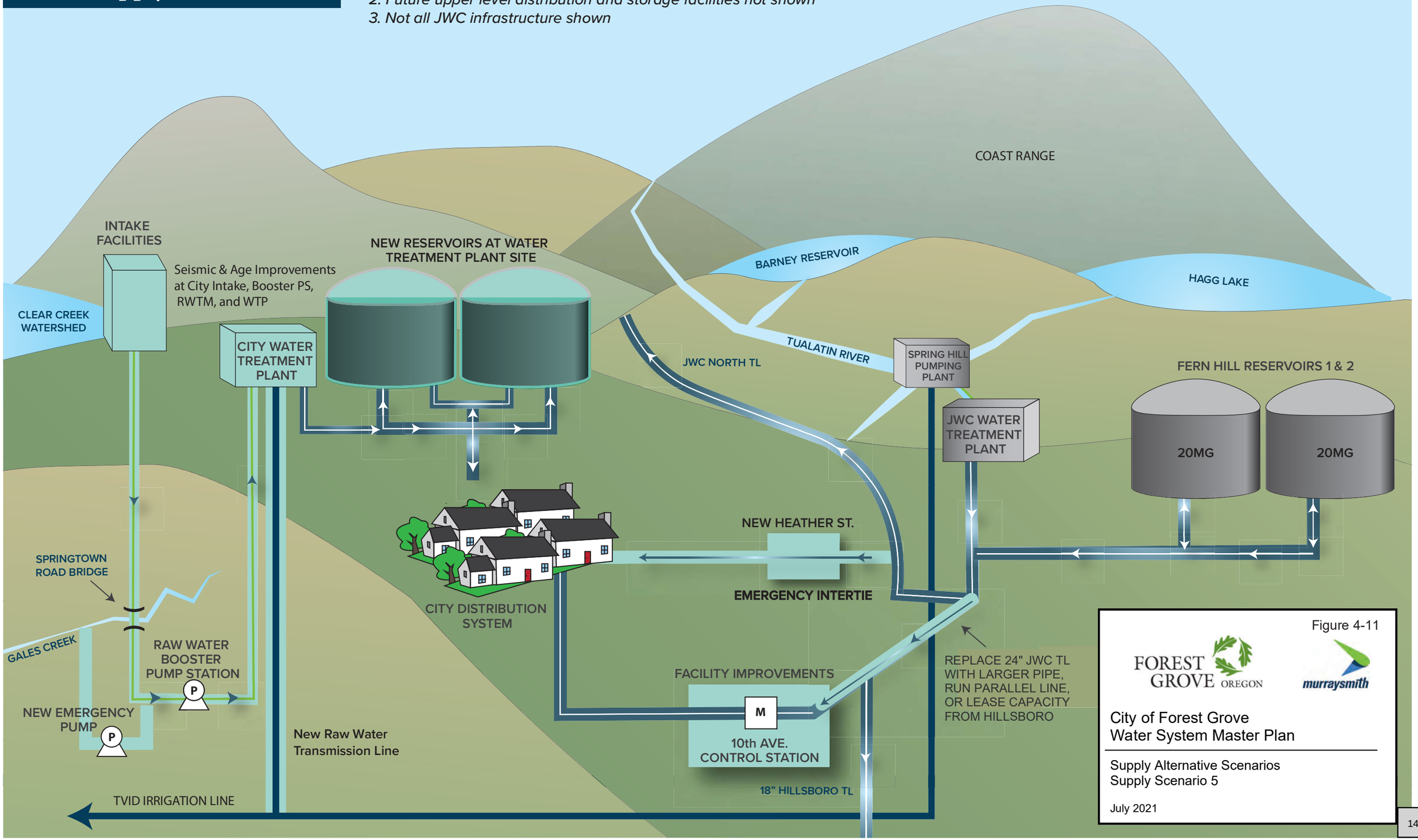


Figure 4-11

FOREST GROVE OREGON

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City of Forest Grove
Water System Master Plan

Supply Alternative Scenarios
Supply Scenario 5

July 2021



Section 5

Section 5

Distribution System Analysis

5.1 Introduction

This section presents an analysis of the City's water distribution system based on criteria outlined in Section 3. The water demand forecasts summarized in Section 2 are used in conjunction with analysis criteria to assess water system performance including service pressures, storage and pumping capacity, and emergency fire flow availability. This section provides the basis for the recommended CIP presented in Section 7.

5.2 Service Pressure and Zone Analysis

5.2.1 Existing Conditions

Under existing PHD conditions, the City's pressure zones, described in Section 1, provide adequate minimum service pressure of at least 30 psi throughout the distribution system. Distribution service pressures can exceed the maximum recommended 80 psi upper pressure limit in some low-lying areas of the 368 Zone, particularly when the 10th Avenue Control Station is used to fill the City's 5 MG Reservoir. High system pressures are also seen along zone boundaries, particularly at lower elevations of the 540 Zone. Small areas of higher pressures in the distribution system are expected, particularly in steep terrain where large differences in topography over short distances make it impractical to serve customers at a narrower range of service pressures. Customers would typically be fitted with individual PRVs to ensure adequate pressure.

5.2.2 Service Area Expansion

As described in Section 2.1.2, the City is planning for growth primarily in three areas northwest of the current city limits: the Purdin Road UGB Area, the David Hill UGB Area, and the DHURA as shown on Plate 1 in Appendix A. The Purdin Road and David Hill UGB Areas are expected to be developed by within the next 20 years, while the DHURA is expected to begin development sometime after. Future service to the DHURA is beyond the 20-year planning horizon for this WSMP and therefore will only be discussed in the context of serving other areas within the UGB.

Most development in the David Hill UGB and Purdin Road UGB Areas is expected to be residential, with some neighborhood mixed use that includes some retail and office space adjacent to the existing service area near the intersection of David Hill Road and Highway 47 and the intersection of David Hill Road and Thatcher Road. Development areas will be looped into existing pressure zones, where applicable. The Purdin Road UGB will be served entirely by the existing 368 Zone. The David Hill UGB will be primarily looped into the existing 368, 435, and 540 Zones with a small

portion to be served by the future 710 Zone. The DHURA will be served by the future 710 and 880 Zones and looped into the existing zones where applicable.

5.3 Storage Analysis

Using the existing and future demands discussed in **Section 2** of this report, the operational, emergency, fire, and total required storage for the water system was calculated using the storage criteria discussed in **Section 3**.

5.3.1 Existing Storage Volumes

The City has existing storage in the 5 MG Reservoir at the City WTP, the David Hill Reservoir, and in the JWC Fern Hill Reservoirs. **Table 5-1** illustrates the available storage for all facilities.

- 5 MG Reservoir - 5.0 MG of available storage. This reservoir also provides chlorine contact time for the City WTP. City staff report a reservoir water depth of 10.58 feet, approximately 1.6 MG, is required for sufficient chlorine contact time as determined by a 2017 tracer study. This volume does not need to be in addition to other storage requirements as long as operating levels do not regularly drop below this minimum.

- David Hill Reservoir - 1.0 MG of available storage.

- JWC Fern Hill Reservoirs – 3.2 MG of available storage. The City owns 13.33% (5.33 MG) of the total 40 MG capacity in the JWC Fern Hill Reservoirs. JWC operations allocate 40% of the total storage to JWC operations, with the remaining 60% available to Cities by ownership percentage, resulting in 3.2 MG of storage available to Forest Grove.

Table 5-1 | Existing Storage Volumes

Facility Name	Owner	Available Capacity (MG)	Zones Served by Gravity
5 MG Reservoir	City	5.0	368
David Hill Reservoir	City	1.0	540, 435, Gales Creek Svc Area
Fern Hill Reservoirs	JWC	3.2	368

Note:

1. The 5 MG Reservoir storage capacity in the 2010 Water System Plan was listed as 4.27 MG. Based on calculations from the original 1980 design drawings, the City's 5 MG Reservoir has a storage volume of closer to 5.2 MG. Due to high uncertainty, the reservoir will be assumed to have a capacity of 5 MG for this analysis.
2. The two Fern Hill Reservoirs in total contain up to 40 MG. The City owns 13.33% (5.33 MG) of which 60% (3.2 MG) is available to the City.

5.3.2 Operational Storage Required

As discussed in **Section 3**, operational storage is calculated as 25 percent of MDD. Pressure Zone 368 is served by operational storage in the 5 MG Reservoir at the City WTP and by the JWC Fern Hill Reservoirs. The 435, 540 Zones, and GCSA are served by operational storage within the David Hill Reservoir. The proposed 710 and 880 Zones are assumed to have operational storage within a

future, higher elevation reservoir. **Table 5-2** shows the required operational storage for the pressure zones served by each storage facility.

Table 5-2 | Operational Storage Required

Zone 368					
Year	2021	2026	2031	2041	2071
MDD (mgd)	5.73	6.20	7.00	8.00	8.82
Operational Storage Required (MG)	1.43	1.55	1.75	2.00	2.20
Zone 435, 540, GCSA					
Year	2021	2026	2031	2041	2071
MDD (mgd)	0.44	0.44	0.60	0.77	1.05
Operational Storage Required (MG)	0.11	0.11	0.15	0.19	0.26
Zone 710, 880					
Year	2021	2026	2031	2041	2071
MDD (mgd)	-	-	-	0.03	0.17
Operational Storage Required (MG)	-	-	-	0.01	0.04

Note:

1. Required operational storage equal to 0.25xMDD. Storage volumes are given to the nearest hundredth (10,000 gallons) and rounding differences are present.
2. Construction of a new reservoir for the 710 and 880 zone will likely be tied to development of the DHURA which is likely to occur more than 20 years from now.
3. Development within the 710 pressure zone in the David Hill UGB will be provided by a constant pressure pumped system, until a future reservoir is constructed to serve the 710 and 880 pressure zones.

5.3.3 Emergency Storage Required

As described in **Section 3.5** emergency storage is required in the event of a loss of supply. Emergency storage is calculated as 100 percent of MDD in City and JWC owned storage. This is an increase from the City's 2010 Water System Plan that used 75 percent of MDD. **Table 5-3** summarizes the emergency storage required by zone.

The 368 Zone is served by gravity from the JWC supply. Therefore, storage in the JWC Fern Hill Reservoirs and the City's 5 MG Reservoir both provide emergency storage in the 368 Zone. The 435 and 540 Zones and GCSA have emergency storage within the David Hill Reservoir. The proposed 710 and 880 Zones are assumed to have emergency storage within a future, higher elevation reservoir.

Table 5-3 | Emergency Storage Required

Zone 368					
Year	2021	2026	2031	2041	2071
MDD (mgd)	5.73	6.20	7.00	8.00	8.82
Emergency Storage Required (MG) - 1xMDD	5.73	6.20	7.00	8.00	8.82
Zone 435, 540, GCSA					
Year	2021	2026	2031	2041	2071
MDD (mgd)	0.44	0.44	0.60	0.77	1.05
Emergency Storage Required (MG) – 1xMDD	0.44	0.44	0.60	0.77	1.05
Zone 710, 880					
Year	2021	2026	2031	2041	2071
MDD (mgd)	-	-	-	0.03	0.17
Emergency Storage Required (MG) - 1xMDD	-	-	-	0.03	0.17

Note:

1. Construction of a new reservoir for the 710 and 880 zones will likely be tied to development of the DHURA which is likely to occur more than 20 years from now.
2. Development within the 710 pressure zone in the David Hill UGB will be provided by a constant pressure pumped system, until a future reservoir is constructed to serve the 710 and 880 pressure zones.

5.3.4 Fire Storage Required

Storage reservoirs must provide sufficient fire storage volume to supply the largest required fire flow in the zone. For this analysis, required fire flow for each zone is selected based on land use as described in Section 3.

Pressure Zone 368 has commercial and industrial customers within the zone boundary. Commercial and industrial customers typically require a higher fire flow rate and longer duration than residential properties. A flow rate of 3,000 gpm at a duration of four hours was assumed for the 368 Zone, consistent with 2019 OFC guidelines for maximum flow from a public water system and City Fire Marshal direction.

Pressure Zones 435, 540, and GCSA are primarily residential. Residential customers require a lower fire flow rate and shorter duration, typically 1,000 gpm for one hour. Oregon House Bill (HB) 2001 Middle Housing, passed in 2019, allows for duplex, triplex, and quadruplex housing within single family residentially zoned areas. This type of housing is considered medium density and has a higher fire flow requirement (2,000 gpm). Therefore, Zones 435, 540, and GCSA are assumed to have a fire flow requirement of 2,000 gpm for two hours.

Table 5-4 shows the total fire storage required based upon the suggested flow rates and durations for the pressure zones. It was assumed that the 435, 540 Zones, and GCSA will be served by the existing 1 MG David Hill Reservoir, and the proposed 710 and 880 Zones will be served by a future reservoir. This analysis assumes only one fire would occur at a time within an area served by a single reservoir.

Table 5-4 | Fire Storage Required

Zone 368		
Fire Flow Req (gpm)	Fire Flow Duration (hrs)	Fire Flow Storage Required (MG)
3000	4	0.72
Zone 435, 540, GCSA		
Fire Flow Req (gpm)	Fire Flow Duration (hrs)	Fire Flow Storage Required (MG)
2000	2	0.24
Zone 710, 880		
Fire Flow Req (gpm)	Fire Flow Duration (hrs)	Fire Flow Storage Required (MG)
2000	2	0.24

Note:

1. Construction of a new reservoir for the 710 and 880 zones will likely be tied to development of the DHURA which is likely to occur more than 20 years from now.
2. Development within the 710 pressure zone in the David Hill UGB will be provided by a constant pressure pumped system, until a future reservoir is constructed to serve the 710 and 880 pressure zones.

5.3.5 JWC Contractual Storage Required

As described in **Section 3.5**, the City's agreement with the JWC partners requires the City to maintain system-wide storage capable of providing three days of the average daily finished water supplied to the City by the JWC system. The JWC requires this storage to minimize fluctuations in demands placed on the JWC treatment and transmission facilities. The City calculated this demand as the difference between projected ADD calculated in **Section 2** and projected City finished water production based on WTP production limitations during non-regulated season and raw water supply during the regulated season.

Total storage includes City storage facilities and the City's 3.2 MG Fern Hill storage capacity ownership. The Fern Hill storage is considered available storage to meet this requirement because the JWC does not allow the reservoir levels to decrease to a point where the capacity would not be available to the City. With the 2020 update to the 10th Avenue Control Station valves, Fern Hill water is available on demand. System-wide JWC contractual storage criteria:

- **Criteria 3 -** JWC contractual guidelines, three times the average daily finished water supplied to the City by the JWC system.

Table 5-5 shows the calculated system-wide storage necessary to comply with JWC requirements.

Table 5-5 | JWC System-wide Storage Required

	2021	2026	2031	2041	2071
ADD (MGD)	3.27	3.52	4.03	4.68	5.33
Projected portion of ADD Supplied by Forest Grove WTP (MGD)[1]	1.96	1.96	1.96	1.96	1.96
Projected Portion of ADD Supplied by JWC (MGD)	1.31	1.56	2.07	2.72	3.37
JWC Storage Required (MG)[2]	3.93	4.68	6.21	8.16	10.12

Note:

1. City provided data for the projected portion of ADD supplied by City WTP.
2. Three times the average daily finished water supplied to the City by the JWC system.

5.3.6 Total System Storage Analysis

Total required system storage is the sum of operational (OS), emergency (ES) and fire storage (FS) components for zones served by each facility. In addition, the City's agreement with the JWC requires a minim total system storage. Total required system storage assumes that Pressure Zone 368 is served by both the 5 MG Reservoir and the City's owned capacity in the JWC Fern Hill Reservoirs. The remaining pressure zones (existing and proposed) are assumed to be served by the 1 MG David Hill Reservoir and future 710 Reservoir. The JWC storage requirements are applied to the entire Forest Grove system, combined.

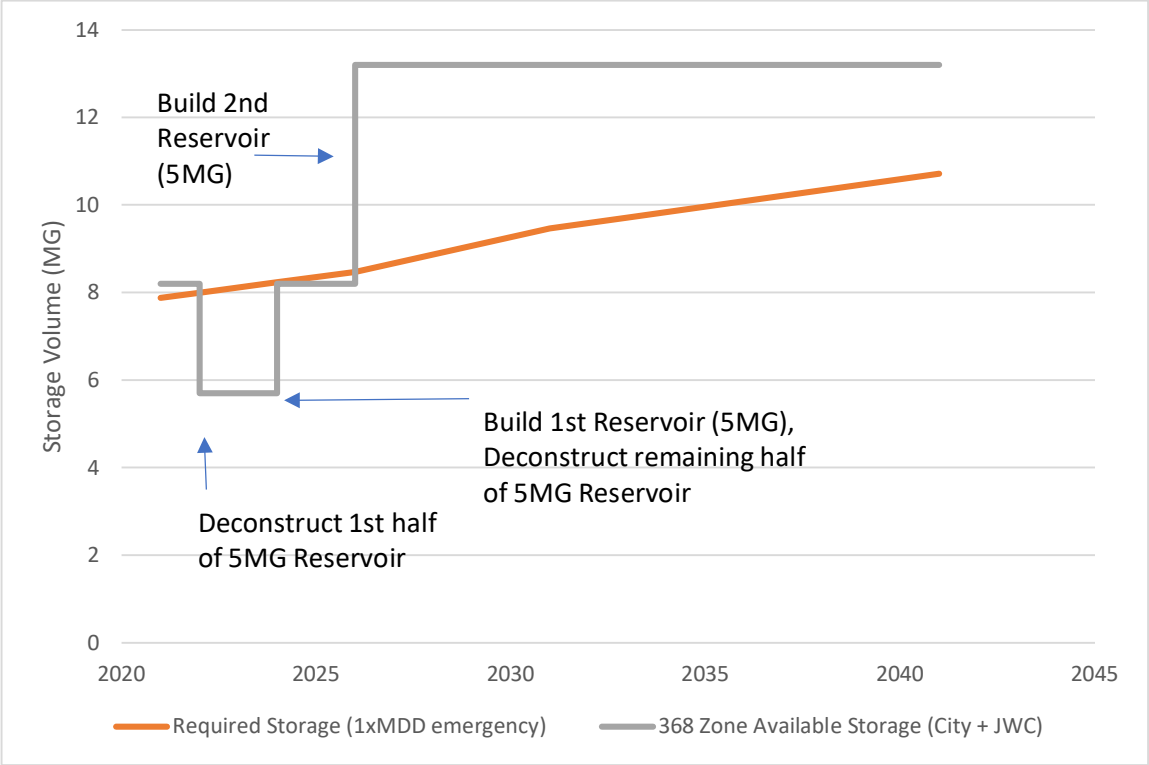
5.3.6.1 Storage Analysis Findings

Additional storage is required at all zones within 20 years. **Table 5-6** and **Figure 5-2, Figure 5-3**, and **Figure 5-4** summarize the storage required by zone. **Table 5-7** and **Figure 5-5** summarizes total system storage needs including JWC requirements and includes proposed additional storage. It was assumed that new storage would be City owned and not through the JWC system.

The 368 Zone is currently barely deficient and will require an additional 3.06 MG in 20 years, and 4.2 MG in 50 years. To meet this deficit, twin 5 MG reservoirs are proposed to replace the existing 5 MG reservoir located at the City WTP. Additionally, the upper zones (435, 540, and GCSA) will reach a storage deficit in 10 years, and by 50 years require an additional 0.56 MG. Pumping and transmission improvements will enable the upper zones to access some of the 368 Zone storage, offsetting the need for additional storage at the David Hill Reservoir. The existing 5 MG Reservoir is critical to current City WTP operations, as it sets the hydraulic grade for the 368 Zone which serves most City water customers and acts as terminal storage for the JWC supply. Operation of half of the existing reservoir could be maintained while the first half is deconstructed, and the first of two new twin 5 MG reservoirs is built. Once finished, the second half of the existing reservoir could be demolished, and the second 5 MG reservoir constructed. **Figure 5-1** illustrates one potential construction phasing of the deconstruction of the existing 5 MG Reservoir by half, and the construction of two Reservoirs. Timing shown may not be feasible given construction limitations. With this phasing, short term deficits will exist and the City may be more vulnerable to supply interruptions.

A 0.5 MG 710 reservoir is recommended to serve high elevation customers, constructed as development requires. This reservoir also provides a benefit to customers in the 540, 435, and GCSA zones as excess storage in this reservoir can be accessed by those customers by gravity. In the short term, small developments at the 710 level may be served by constant pressure pumping from the 540 Zone, as described in the next section. Long term, however, a reservoir is recommended to best serve these customers. Timing on this reservoir is primarily dependent on development.

Figure 5-1 | Phased Construction of 368 Zone Storage



Note:

1. This is only one possible construction schedule. Actual construction timeline will vary.

Table 5-6 | Storage Requirements and Deficit by Pressure Zone (MG)

Year	Demand (MG)		Existing Storage (MG)		Required Storage (MG)				
	Avg (ADD)	Max (MDD)	City	JWC	Operating (OS)	Emergency (ES)	Fire (FS)	Total Storage	Surplus/ (Need)
368									
2021	3.03	5.73	5	3.2	1.43	5.73	0.72	7.88	0.32
2026	3.28	6.20	5	3.2	1.55	6.20	0.72	8.47	(0.27)
2031	3.72	7.00	5	3.2	1.75	7.00	0.72	9.46	(1.26)
2041	4.27	8.00	5	3.2	2.00	8.00	0.72	10.72	(2.52)
2071	4.72	8.82	5	3.2	2.20	8.82	0.72	11.74	(3.54)
435, 540, GCSA									
2021	0.23	0.44	1	0	0.11	0.44	0.24	0.79	0.21
2026	0.23	0.44	1	0	0.11	0.44	0.24	0.79	0.21
2031	0.31	0.60	1	0	0.15	0.60	0.24	0.99	0.01
2041	0.39	0.77	1	0	0.19	0.77	0.24	1.20	(0.20)
2071	0.53	1.05	1	0	0.26	1.05	0.24	1.55	(0.55)
710, 880									
2021	-	-	0	0	-	-	-	-	-
2026	-	-	0	0	-	-	-	-	-
2031	-	-	0	0	-	-	-	-	-
2041	0.01	0.03	0	0	0.01	0.03	0.24	0.27	(0.27)
2071	0.08	0.17	0	0	0.04	0.17	0.24	0.45	(0.45)

Note:

1. Storage calculations in the 368 zone include 3.2 MG City-owned storage capacity in JWC Fern Hill Reservoirs.
2. Negative values are shown in parentheses and indicate a deficit.
3. Zones 710 and 880 are proposed to serve future development and have no existing storage.
4. Construction of a new reservoir for the 710 and 880 zone will likely be tied to development of the DHURA which is likely to occur more than 20 years from now.
5. Development within the 710 pressure zone in the David Hill UGB will be provided by a constant pressure pumped system, until a future reservoir is constructed to serve the 710 and 880 pressure zones.

Figure 5-2 | 368 Zone Storage Requirements

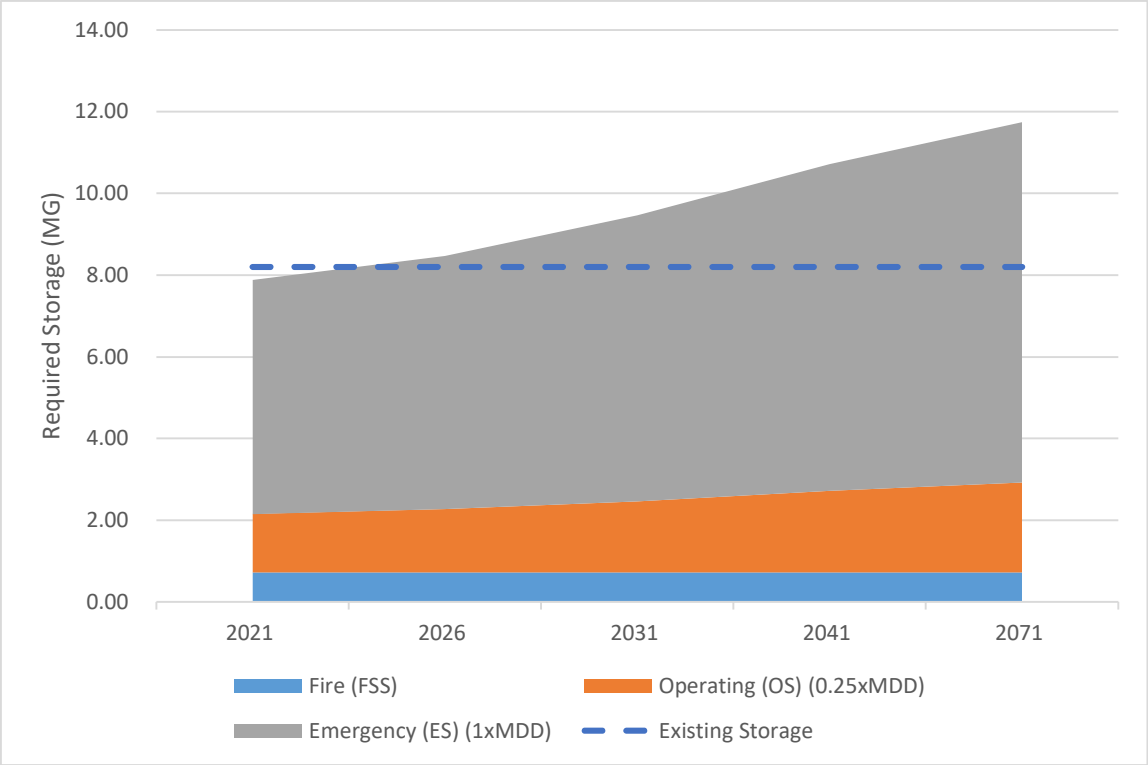


Figure 5-3 | 435, 540, and GCSA Zone Storage Requirements

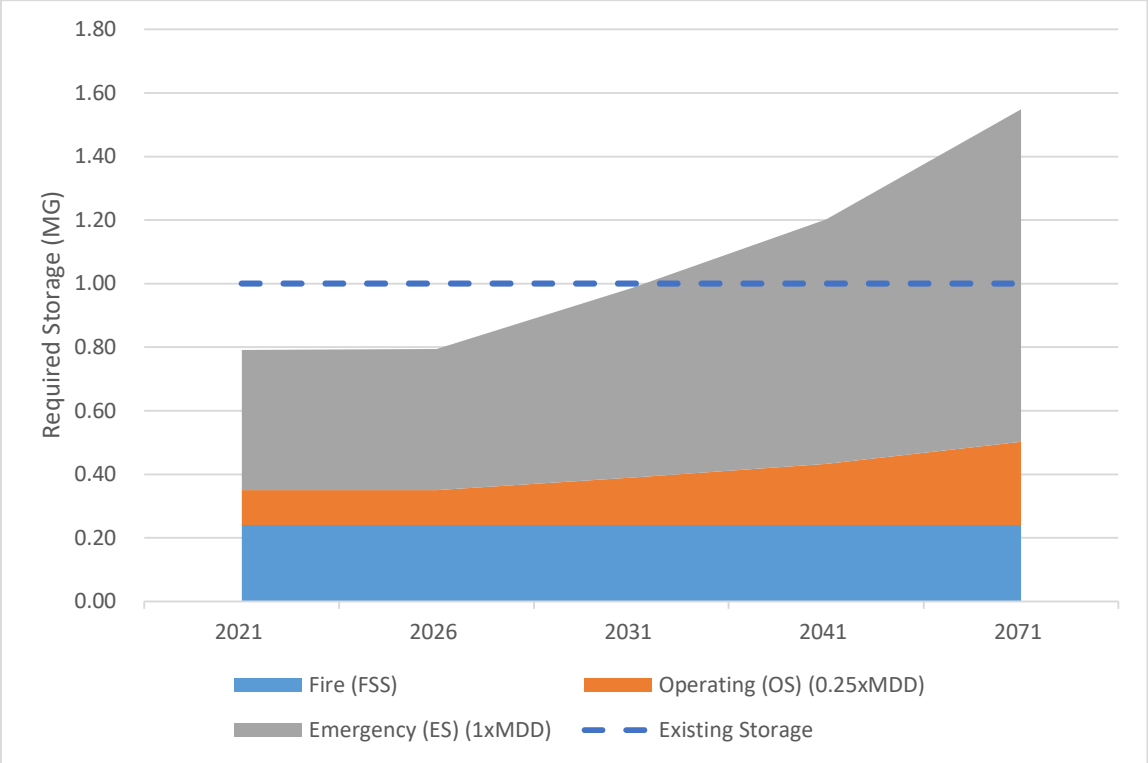
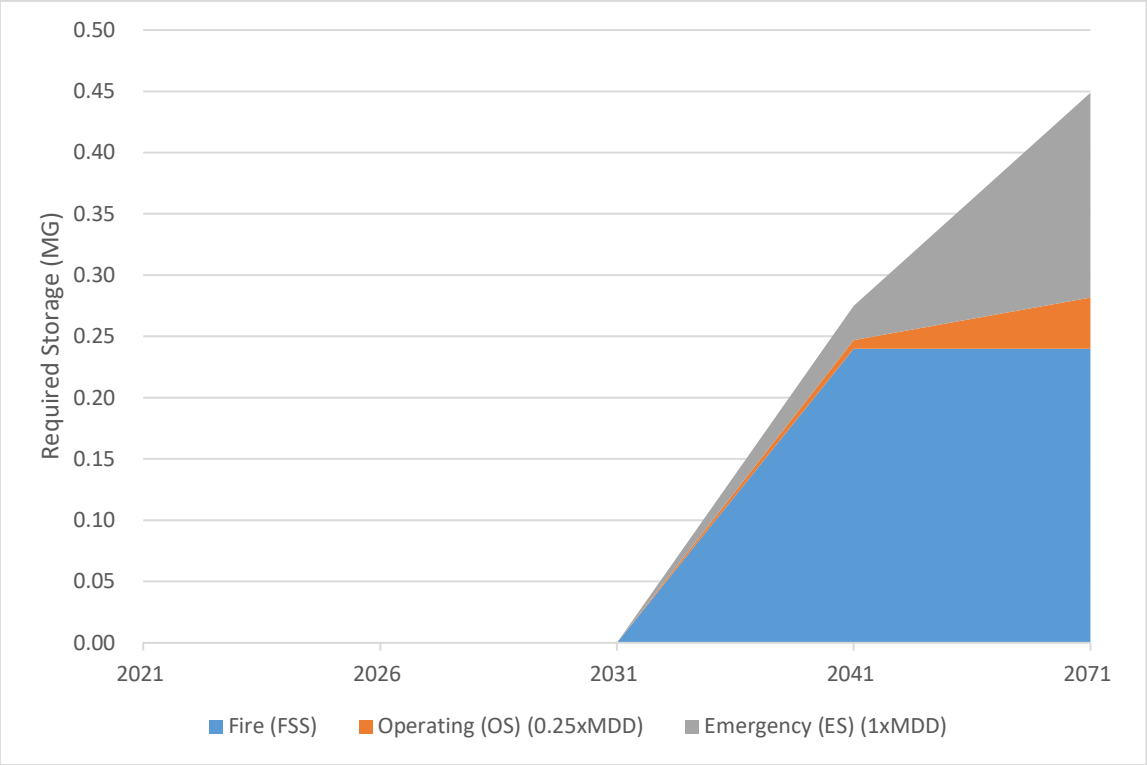


Figure 5-4 | 710 and 880 Zone Storage Requirements



Note:

1. No existing 710 or 880 storage facilities. Prior to construction of 710 Reservoir, supply to be provided by David Hill Reservoir.

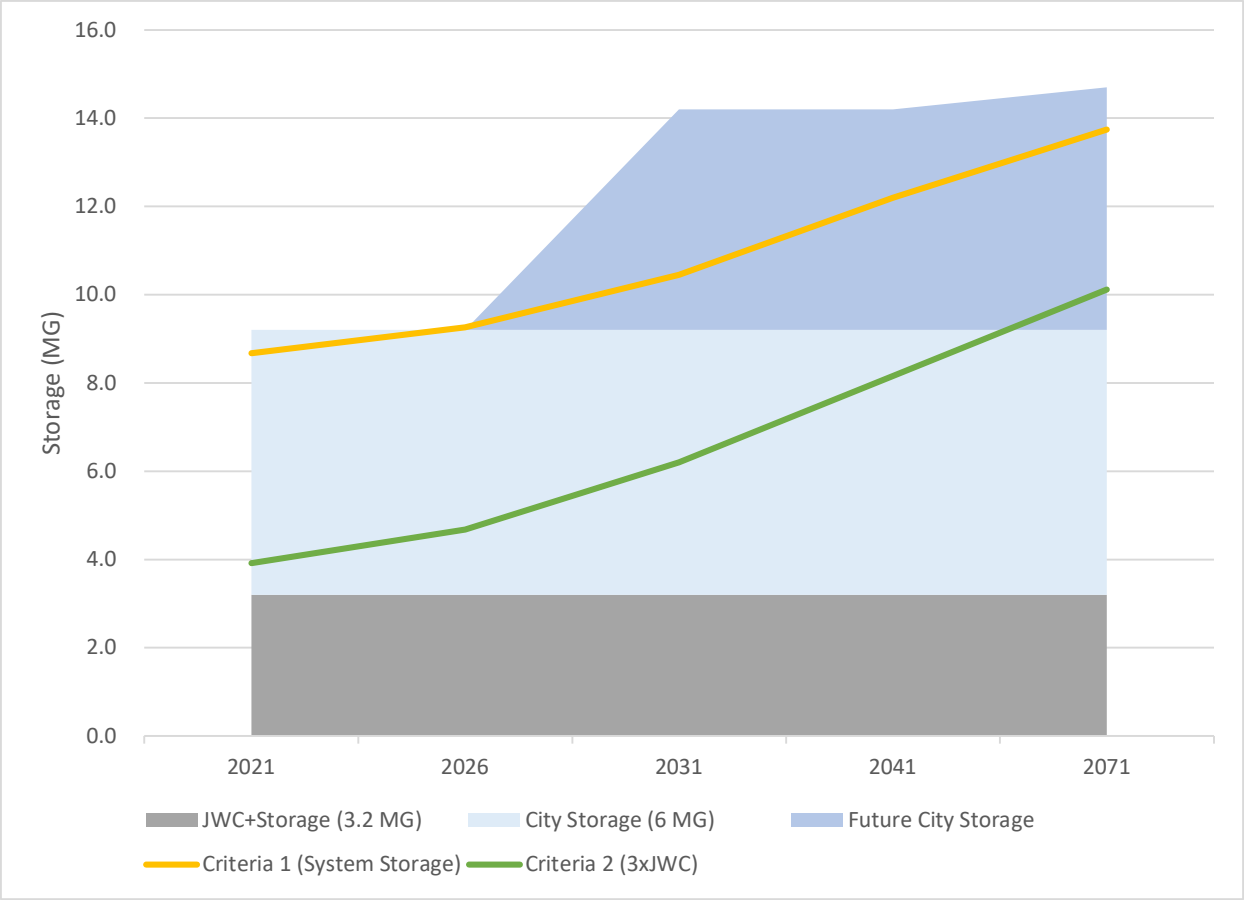
Table 5-7 | Total Storage Deficiencies

Year	Existing Storage (MG)		Criteria 1 – System Storage Requirements (MG)		Criteria 2 – JWC In-System Storage (MG)	
	City	JWC	Total Required (Table 5-6)	Surplus/ (Need)	Total Required (Table 5-5)	Surplus/ (Need)
2021	6.00	3.20	8.67	0.53	3.92	5.28
2026	6.00	3.20	9.26	(0.06)	4.68	4.52
2031	6.00	3.20	10.45	(1.25)	6.20	3.00
2041	6.00	3.20	12.19	(2.99)	8.16	1.04
2071	6.00	3.20	13.74	(4.54)	10.12	(0.92)

Note:

1. Negative values shown in parentheses indicate a deficit.

Figure 5-5 | Total Storage Deficiencies and Proposed Storage



Note:

1. City Storage includes both the 5 MG Reservoir and the 1 MG David Hill Reservoir.
2. Future City Storage includes a second 5 MG Reservoir, in addition to the replacement of the existing 5 MG Reservoir, and a new 0.5 MG 710 Reservoir.

5.4 Pumping Analysis

5.4.1 Capacity

As presented in **Section 3**, the City's required pumping capacity varies depending on the water demand, volume of available storage, and the number of pumping facilities serving each pressure zone. Required firm capacity is defined as a station's total pumping capacity with the largest pump out of service. Pumping capacity is evaluated for these two configurations.

- Pumping to storage
  - Required firm capacity (largest pump out of service) = MDD for zones served
  - Applies to:
    - David Hill PS and Watercrest PS
    - Proposed future 710 Zone PS after a proposed 710 reservoir is constructed

- **Constant pressure pumping – sole supply to customers**
  - Required firm capacity = PHD for zones served + largest required fire flow
  - Applies to proposed service areas above the existing 540 Zone, including:
    - proposed future 710 Zone prior to proposed 710 reservoir construction
    - proposed 880 Zone

Existing and projected future pumping capacity requirements are summarized in **Table 5-8**.

Table 5-8 | Pumping Capacity Analysis

Pump Station Name	Service Type	Criteria	Existing Capacity (gpm)	Zones Served	Year	Required Capacity (gpm)	Surplus/ (Need) (gpm)
Watercrest & David Hill	To Storage	MDD	1,080 Total 680 Firm	540, 435, GCSA, Future 710 and 880	2021	307	373
					2026	308	372
					2031	415	265
					2041	554	126
					2071	843	(163)
Future 710 (pre-reservoir)	Constant Pressure Supply	PHD + 2,000 gpm max fire flow	NA	Future 710 and 880	2021	NA	NA
					2026	2,000	(2,000)
					2031	2,000	(2,000)
					2041	2,039	(2,039)
					2071	2,232	(2,232)
Future 710 (post-reservoir)	To Storage	MDD	NA	Future 710 and 880	2021	-	-
					2026	-	-
					2031	-	-
					2041	19	(19)
					2071	116	(116)
Future 880 (post-reservoir)	Constant Pressure Supply	PHD + 2,000 gpm max fire flow	NA	Future 880	2021	-	-
					2026	-	-
					2031	-	-
					2041	-	-
					2071	2,070	(2,070)

Note:

1. Negative values shown in parentheses indicate a deficit.
2. Watercrest PS is a single pump at 280 gpm capacity. David Hill PS has two pumps at 400 gpm each. Firm capacity in this scenario assumes the largest pump of the three available pumps is out of service, one pump is active at each station.
3. Pump stations must provide adequate supply for all zones where one zone acts as a source for another. While the Watercrest and David Hill Pump Stations only directly supply the 540 Zone, they must also provide MDD for higher zones which are supplied through pumping or PRVs from the 540 Zone.
4. It is assumed that the 880 PS draws suction supply from the 710 Zone. Prior to construction of the future 710 Reservoir, the 710 PS will be required to simultaneously provide PHD and fire flow for both the 710 and 880 Zones. The timing of 710 Reservoir construction is unknown, therefore 880 Zone pumping demands are shown under both operating conditions (with 710 Reservoir and without) for all years.

5.4.2 Upper Zone Supply

Pumping is required for service to the City's existing upper zones (above 368 Zone). Currently, the City relies on the Watercrest PS to supply the 540 and 435 Zones and GCSA, with backup supply from the David Hill PS. Additional demand will be placed on these pump stations as the City expands into the David Hill UGB and DHURA areas.

As shown in Table 5-8, there is no expected pumping capacity deficit to upper zones within 20 years. However, there is currently no provision for back-up power at the David Hill Pump Stations making it vulnerable to a power outage. The City has indicated the Watercrest pump station is backed up by the emergency generator at the City WTP. It is recommended that the City maintains back-up power for at least one of the pump stations, if not both, so the David Hill Reservoir can continue to be filled during a power outage. This will be particularly important as development accelerates in the David Hill area. Increased water demand from future development here will be reliant on these pump stations and the David Hill Reservoir for water service.

The Watercrest Pump Station operates with a single pump. It is recommended that the City evaluate upgrading equipment at this pump station to include a redundant pump. David Hill Pump Station may be considered the redundant pump for Watercrest. In this case, the David Hill Pump Station should be exercised regularly to confirm it will be ready to operate in case of a mechanical issue at the Watercrest Pump Station.

5.4.3 Future 710 and 880 Zone Supply

To provide adequate service pressure to customers, the David Hill UGB area will require a maximum HGL of 710 feet, while the DHURA will require a maximum HGL of 880 feet. The City is currently in the preliminary planning phase for development of the UGB area. The DHURA is not expected to develop within the next 20 years. There are several water service options to meet this uncertain development timeframe.

The proposed 710 service area within the UGB is limited in size and thus a small constant pressure pump station, located near the existing David Hill Reservoir, can effectively serve areas between approximately 480 feet and 600 feet at an HGL of 710 feet. An upper-level reservoir could later be constructed at this 710-foot HGL to provide gravity supply to the 710 Zone and the constant pressure pump station could transition to pump to storage. The highest elevations in the DHURA could then be served by a new constant pressure pump station at an approximate HGL of 880 feet. This new pump station would pull suction supply from either the 710 Reservoir, or the existing David Hill Reservoir, depending on the location of future development and the proposed 710 Reservoir.

Prior to construction of the 710 Reservoir, the 710 PS would need to provide increased capacity to supply peak hour and fire flow demands without the benefit of gravity storage. Once the 710 Reservoir is constructed, pumping capacity requirements will decrease as the reservoir will provide fire flow capacity. Both pump station operational conditions (pre- and post-710 Reservoir) are

provided in Table 5-8. As the timing of 710 Reservoir construction is unknown, both operational conditions are shown for the 710 PS for the entire planning period. Required pumping capacity shown in Table 5-8 is based on projected demands for both the 710 and 880 pressure zones over the 20-year planning horizon consistent with demand projections in Section 2. The 50-year planning horizon is also shown for reference. Ultimate design capacity for a proposed 710 PS will be determined by the actual service area selected and refined demand projections developed during the pre-design process. It is recommended the proposed constant pressure pump station be designed with on-site back-up power with automatic transfer switches.

5.4.4 Future Service Elevations between Zones

As described in Section 1.4 and 5.2.2, proposed future pressure zone HGLs were established based on existing ground elevations taken from topographic mapping and service pressure criteria documented in Section 3. Pressure zone boundaries and HGLs are chosen to serve the widest range of customer elevations with the City's future service area with the minimum number of new zones. This approach maximizes distribution system looping for capacity and water quality and minimizes the need for new facilities such as reservoir and pump stations. This can also leave a narrow band of elevation in undeveloped areas where future customers may fall between two zones, receiving higher than normal pressure from the higher HGL zone and lower than normal pressure from the lower HGL zone.

Existing ground elevations in the David Hill UGB and DHURA include a narrow band between 440 and 480 feet which falls between zones. Customers up to 440 feet are served by the David Hill Reservoir and existing 540 Zone. Customer above 480 feet are served from the proposed 710 Zone to be supplied by a proposed constant pressure pump station in the short term and a future 710 Reservoir in the long term. Service to future customers between the 540 and 710 zones should be evaluated at the time a site plan is proposed for the development. Actual water service elevations will be dependent on site grading and structure placement on each developed property. If service elevations remain in the 440 to 480-foot range between zones, the following service options should be considered to supply these customers with an HGL of approximately 600 feet.

- *PRVs* – water supplied from the proposed 710 Zone routed through pressure reducing valves on individual services as needed or a single PRV on a distribution main serving multiple customers in this range

- *Optimize 710 Pump Station* – a constant pressure pump station proposed to supply an approximate 710 HGL to future 710 Zone customers adjacent to this elevation range could be optimized using variable frequency drives (VFDs) to serve a broader range of elevations or a narrow set of elevations most likely to develop prior to 710 Reservoir construction. VFDs are already required for constant pressure pumping so this approach does not add mechanical cost to the proposed pump station

5.5 Distribution Capacity and Hydraulic Performance

5.5.1 Hydraulic Model

A steady-state hydraulic network analysis model was used to evaluate the performance of the City's existing distribution system and evaluate proposed piping improvements based on hydraulic performance criteria described in Section 3. The purpose of the model is to determine pressure and flow relationships throughout the distribution system for average and peak day water demands under existing and projected future conditions. Modeled pipes are shown as "links" between "nodes" which represent pipeline junctions or pipe size changes. Diameter, length, and head loss coefficients are specified for each pipe and an approximate ground elevation is specified for each node.

The hydraulic model was developed for this WSMP using the InfoWater modeling software platform with GIS water system mapping and operations data provided by the City. Model software selection is documented in Appendix F. The model was calibrated using data from fire hydrant flow tests conducted specifically for model calibration. Model analysis scenarios were created to evaluate existing and projected 20-year demands. A complete description of calibration and results is available in Appendix G.

5.5.2 Modeled Water Demands

5.5.2.1 Existing Service Area

Existing water demands are assigned to the model geographically based on customer billing address and billed water consumption. Future residential/multifamily demand in the existing water service area is assigned by scaling up the existing demand distribution. Future demand in the existing system due to development of non-residential areas identified in the EOA were assigned to adjacent junctions. Future demand in new developments are uniformly distributed across new junctions, based on the areas projected demand.

5.5.3 Model Calibration

Model calibration typically involves adjusting the model parameters such that pressure and flow results from the model more closely reflect field pressures throughout the City's distribution system. This calibration process tests the accuracy of model pipeline friction factors, demand distribution, valve status, network configuration, and facility parameters such as reservoir elevations and pump curves. The required level of model accuracy can vary according to the intended use of the model, the type and size of water system, the available data, and the way the system is controlled and operated.

To calibrate the model, pressure and flow measurements are recorded at chosen fire hydrants throughout the distribution system during flow testing. Fire flow testing "stresses" the system by flowing a hydrant and monitoring system pressure drops due to that flow. Boundary condition

data, such as reservoir levels and pump on/off status, must also be known to accurately model the system conditions during the time of the flow test. Flow testing was performed in November of 2018, and February of 2019.

5.5.3.1 10th Avenue Control Station Assumptions

Supply from the JWC is currently only available through the 10th Avenue Control Station. The station control valves were replaced in July 2020 with dual purpose flow and pressure control valves, typically operated under pressure control. Prior to 2020, the station had flow control valves with mechanical pressure modes. For analysis purposes, the valves are modeled as pressure reducing valves at 80 PSI when supplying the system, or 40 PSI when operating as emergency supply only. Although this is not how the Control Station was operated or modeled during calibration, this assumption does not significantly impact calibration results and is representative of current operations.

For any water system, a portion of the data describing the distribution system will be missing or inaccurate, or the system operation will change with future development, and assumptions will be required. This does not necessarily mean the accuracy of the hydraulic model will be compromised, as is the case for the 10th Avenue Control Station. Models that do not meet the highest degree of calibration can still be useful for planning purposes.

5.5.3.2 Steady State Calibration Results

The model calibration's confidence level was evaluated based on the difference between modeled and field-measured pressure drops during fire hydrant flow testing, measured in psi, as summarized in **Table 5-9.** Overall system calibration confidence is considered medium to high.

Table 5-9 | Calibration Results Averaged by Zone

Zone	Static Pressure Percent Error	Residual Fire Flow Pressure Difference (PSI)	Confidence Level
368 - Average	5%	-5	Medium/High
368 - JWC Supply	5%	-4	Medium/High
368 - WTP Supply	5%	-6	Medium/High
435	5%	-5	Medium/High
540	<1%	-5	High
Gales Creek[1]	N/A	N/A	N/A
435 – Valley Crest Way PRV[2]	N/A	N/A	N/A

Note:

1. No flow tests recorded in the GCSA.
2. Small subzone supplying <20 homes. No flow tests conducted here.
3. Complete results available in the Calibration Memo, included in **Appendix G**.

5.5.4 Fire Flow Analysis

Fire flow scenarios test the distribution system's ability to provide required fire flows at a given location while simultaneously supplying MDD and maintaining a minimum residual service pressure of 20 psi at all services. Required fire flows are assigned based on the zoning surrounding each hydrant as summarized in Section 3. Deficiencies within 10% of the required flow are assumed within the error range of the model. Gales Creek was not evaluated.

The system was analyzed under existing MDD and projected 20-year (2041) MDD conditions. Only areas within the UGB were assumed to be developed and have water demand within 20 years, consistent with future demand projections described in Section 2.

5.5.4.1 Operating Conditions

5.5.4.1.1 Heather Street Control Station (NTL Emergency Fire Flow Connection)

The City is currently designing an emergency intertie station, the Heather Street Control Station, with the 72-inch JWC NTL which passes through the western boundary of the City water service area. This control station will have combination pressure and flow control valves like those at the 10th Avenue Control Station. As described in Section 4, the City does not own capacity in the 72-inch JWC NTL and will be leasing capacity from other JWC partners on an emergency basis. For this analysis, it is assumed that this connection is available under future emergency conditions and is operated based on pressure. The pressure is set low enough (40 PSI) so that the valve does not open under non-emergency conditions.

5.5.4.1.2 10th Avenue Control Station

For this analysis, it is assumed that this connection will be operating on pressure control and therefore will be available to supply fire flow, even if the primary system supply is the WTP. The station control valves will open under low pressure (similar 40 PSI setting as Heather St Control) even if the system is being supplied primarily by the City's WTP during the event.

5.5.4.1.3 System Storage

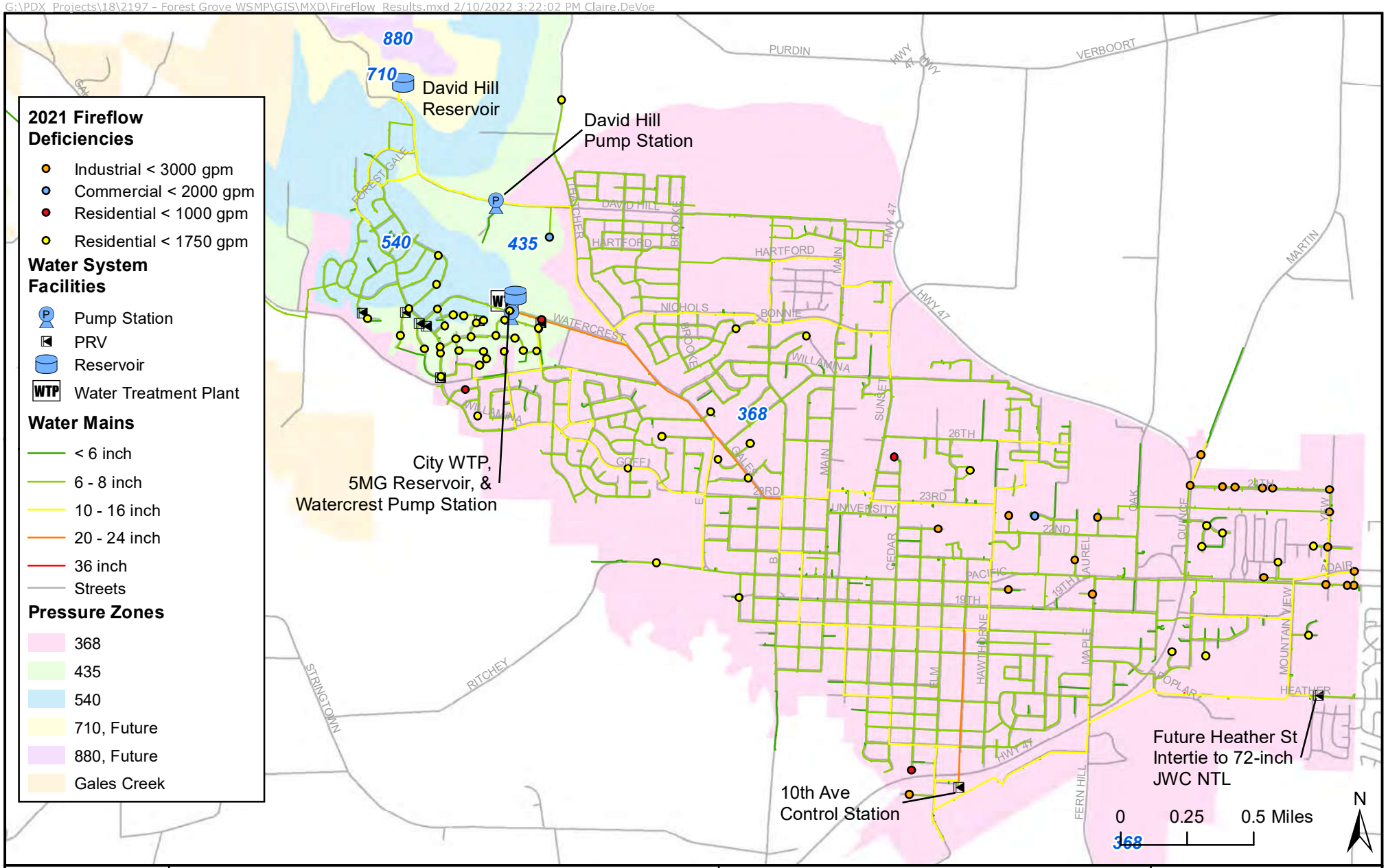
The David Hill and 5 MG Reservoirs are assumed to be operating at 50% full. This is a slightly more conservative estimate of all operational and fire storage depleted and only emergency storage capacity available. Emergency storage is assumed to be 1xMDD. It is assumed the 5 MG Reservoir is replaced with two, 5 MG Reservoirs. JWC storage is included in the 368 Zone requirements. Pumping from the twin 5 MG Reservoirs will be available to meet future 540 Zone emergency storage. However, in a more conservative estimate, it was assumed no pumping available.

5.5.4.2 Fire Flow Analysis Results

The City's distribution system is generally well looped with multiple PRVs or supplies serving each pressure zone. Adequate fire flow is generally available under 2021 MDD conditions throughout

the existing distribution system with slightly less flow available at the boundary between pressure zones for fireflow demands less than 3,000 gpm. For industrial fire flows (3,000 gpm), especially in the northeast corner of the system, fireflow is limited, primarily due to pipe size restrictions. Figure 5-6 illustrates fire flow deficiencies under 2021 MDD.

These deficiencies are exacerbated under 2041 MDD conditions. Transmission upsizing between the JWC control valves and the City WTP improve most deficiencies and isolated piping upsizing or system looping address most of the remaining deficiencies. Additional improvements are listed in Section 7. Figure 5-7 illustrates fire flow deficiencies under 2041 without system improvements. Additional fire flow availability maps are included in Appendix J, System Wide Fire Flow Availability.

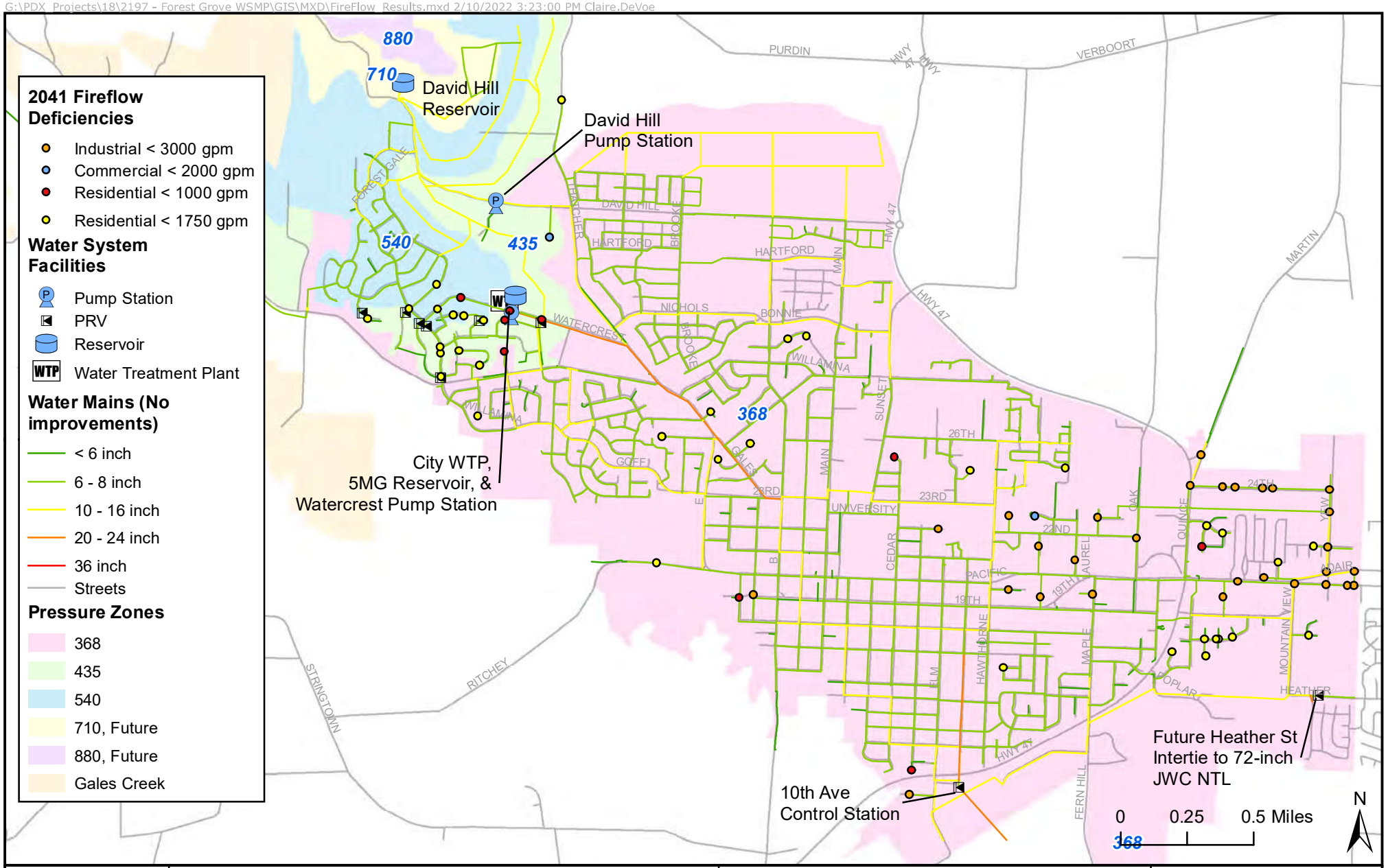


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City of Forest Grove
Water System Master Plan

Figure 5.6
Hydraulic Model Calibration
2021 Fire Flow Deficiencies

FOREST GROVE ORE



City of Forest Grove
Water System Master Plan

Figure 5.7
Hydraulic Model Calibration
2041 Fire Flow Deficiencies
No Improvements

5.5.5 JWC Supply Transmission to 5 MG Reservoir

5.5.5.1 Model Results

As previously discussed, the City relies on the existing 10th Avenue Control Station to provide adequate supply from the JWC to meet peak summer season demands and maintain the water level in the 5 MG Reservoir. Finished water stored in the 5 MG Reservoir should also provide operational storage to set the HGL and maintain system pressures in the 368 Zone during fluctuations in demand throughout the day. JWC flow through 10th Avenue is transmitted to the City's 5 MG Reservoir through the distribution system. Hydraulic modeling of JWC supply during peak demands indicates:

- *368 Zone HGL* - The 10th Avenue Control Station pressure control valves are maintaining zone pressure during peak demand, rather than the 5 MG Reservoir.

- *368 Zone Service Pressure* – To refill the 5 MG reservoir during high demand, the pressure at the control valves also needs to increase. These higher flow rates create excessive distribution system pressures over 100 psi for the lowest elevation customers in the 368 Zone which are also closest to the Control Station.

These model findings are consistent with water utility staff observations of system pressures and reservoir filling from the JWC supply through 10th Avenue Control Station.

5.5.5.2 System Concerns

Model results described in the prior section suggest a few vulnerabilities in the City's existing JWC supply and distribution system.

1. *Undersized distribution mains* - Portions of the distribution system between the 10th Avenue Control Station and 5 MG Reservoir are undersized, limiting available flow. This may inhibit the City's ability to refill the reservoir quickly from JWC supply.

2. *5 MG Reservoir draw down* - The existing 5 MG Reservoir has a narrow hydraulic operating range (draw down) meaning the existing reservoir water level cannot be lowered very much without having inadequate pressure at the highest elevations of the 368 Zone closest to the City WTP. It is anticipated that this issue will become more pronounced as demands grow and the existing reservoir volume does not meet required storage capacity as shown in Table 5-6.

3. *Low elevation and high pressure near JWC supply point* - 368 Zone customers near the 10th Avenue Control Station are at the lowest elevations in the City system. Thus, service pressures are already on the high end of the normal range. This means that with existing infrastructure, even small increases in pressure due to higher JWC flows, as noted above in System Concern 1, will more easily exceed the normal service pressure range which could lead to customer plumbing fixture damage from overpressure.

5.5.5.3 Mitigation Strategies

To mitigate system concerns presented in the prior section, the City could implement one of the following strategies. Strategy 2, replace the 5 MG Reservoir at the same overflow elevation and upsize transmission, is the preferred strategy as it limits system changes and improves distribution transmission as well.

- ***Strategy 1*** - Replace the 5 MG Reservoir at the same overflow elevation and move the 368 Zone upper service elevation boundary down to a lower elevation. This would add customer demand to upper zones and allow a reduced HGL in the 368 Zone and more draw down in the new reservoir at the WTP site. This strategy would require more capacity in pumping and storage for upper zones.

- ***Strategy 2*** – Replace the 5 MG Reservoir at the same overflow elevation and upsize transmission from 10th Avenue Control Station to the 5 MG Reservoir. Upsizing transmission along this route to 20 inches allows for continued operations with a reservoir overflow of 368 feet. High pressures will remain a concern at low elevations in the 368 Zone during high supply but can be mitigated with controlled reservoir operations and slower reservoir filling rates. For some of the lowest elevation customers, individual PRVs are recommended, if they do not already exist.

5.5.5.4 Heather Street Control Station Flows

As discussed in Section 4, the City is currently designing an emergency intertie with the 72-inch JWC NTL called the Heather Street Control Station near Heather Street and Mountain View Drive at the east end of the City system. Hydraulic challenges at the Heather Street JWC supply connection are similar to those system concerns described in Section 5.5.5.2. The area around Heather Street has some of the lowest elevations in the system which receive service pressure on the high end of the normal range. Modeling indicates that higher flow rates, over approximately 2,250 gpm, through the proposed intertie will drive pressures over 100 psi locally. Several operating scenarios were modeled for the proposed Heather Street Control Station under existing MDD. Modeling scenarios included upsized distribution mains to the 5 MG Reservoir, testing fixed control station flow rates, and testing pressure constraints. The results are summarized in Table 5-10.

Upsizing existing distribution mains from the Heather Street Control Station to provide a continuous 20-inch diameter transmission route to the 5 MG Reservoir linked into the existing system appears to provide the best benefit by both minimizing pressure increases and maximizing flows. However, at very high flows, building a separate 24-inch transmission may mitigate some distribution system overpressurization for customers near the Heather Street Intertie, when compared with a 20-inch connected alternative.

Table 5-10 | Heather Street Control Station Flow Analysis

Distribution Piping Improvements	Limit flow velocity to 14 fps or 7,000 gpm		Available Flow at Heather Street (gpm)	
	Available Flow at Heather Street (gpm)	Pressure at Heather Street (psi)	Pressure limited to 100 psi	Pressure limited to 85 psi
No changes, existing distribution	3,500	120	2,250	500
24-inch dedicated transmission to 5 MG Reservoir	7,000	100	7,000	50
Continuous 20-inch, replace all existing transmission <20-inch diameter to 5 MG Res	7,000	117	5,000	1,000

5.6 Distribution System Water Quality

The City meets all current drinking water quality regulations. The following summary includes microbial contaminants (Total Coliform Rule), lead and copper (Lead and Copper Rule) and disinfection by-products (Stage 2 Disinfectants and Disinfection Byproducts Rule) which may be exacerbated or originate in the distribution system.

5.6.1 Total Coliform Rule Compliance

The City is currently meeting all applicable requirements for the Total Coliform Rule. It is important to maintain active circulation of water throughout the distribution system, in both pipes and reservoirs to retain a chlorine residual. The absence of chlorine residual and accumulation of sediments contribute to bacterial growth, which in turn can result in failure to comply with this rule. As of December 1, 2020, the City tests 30 routine coliform samples per month.

5.6.2 Lead and Copper Rule Compliance

Under the Lead and Copper Rule drinking water providers are required to test for lead in the distribution system and manage the hydrogen potential (pH) of water supplies to reduce corrosion of pipes and fixtures which can release lead into drinking water. Forest Grove is in compliance with the Lead and Copper Rule. The JWC WTP uses caustic soda to raise the pH of treated water supplied to City customers and reduce corrosion. The City tests for lead at 30 customer taps on a 3-year cycle. In 2020 testing of 30 test sites, 17 showed no lead detected and all were less than 0.0072 milligrams per liter (mg/L), well below the regulated action level of 0.015 mg/L. Copper testing showed similarly low levels in all 30 tests. There are no concerns with future compliance with the Lead and Copper Rule.

5.6.3 Stage 2 Disinfectants and Disinfection Byproducts Rule (D/DBPR) Compliance

Disinfection byproducts (DBP) form when disinfectants, like chlorine used to kill harmful bacteria and reduce water borne illness, react with naturally occurring compounds in the source water. All commonly used disinfectants form DBPs. Research has linked high concentrations of DBPs to increased risk of cancer. DBPs are regulated to a maximum contaminant level (MCL) which is considered safe. Currently, the City conducts quarterly sampling for DBPs at two sample sites, both of which are currently in compliance. City testing consistently shows trihalomethanes (TTHM) levels at less than one third to one quarter of the MCL and haloacetic acids (HAA5) levels less averaging less than two thirds of the MCL.

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Section 6

Section 6

Seismic Resiliency Plan Summary

6.1 Introduction

This section presents a summary of the September 2020 Forest Grove Water System Seismic Resiliency Plan (SRP, InfraTerra 2020) included in Appendix H. The SRP fulfills the seismic requirements for Water Master Plans in OAR 333-061-0060(5) (J) and recommends mitigation measures that can be implemented over the next 50 years to improve seismic resilience of the water system. The findings and recommendations listed in this section are summarized from InfraTerra's SRP and not from work performed by Murraysmith.

Findings and recommendations from the SRP are also referenced in Section 4 and Section 5 of this WSMP. Section 7 includes seismic mitigation projects recommended in the SRP.

6.2 Performance Objectives

Seismic performance objectives developed for the City water system are guided by the ORP which was developed by the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) under the 2011 House Resolution 3 by the Oregon House of Representatives. The ORP sets policy direction for owners of infrastructure to protect lives and maintain economic and commercial activity following a Moment Magnitude 9.0 (M9) earthquake on the Cascadia Subduction Zone (CSZ).

Recognizing the high cost of infrastructure improvements, the ORP recommends a phased approach for improving seismic resilience. The approach includes identification and hardening of key supply, transmission, and distribution facilities (backbone) so that water is available for critical needs such as fire suppression, health and emergency response, and drinking water at key distribution points immediately after the earthquake while damage to the rest of the water system is repaired. The identified backbone for the City water system includes:

- RWTM – supply to City WTP
- City WTP
- 5 MG Reservoir at City WTP
- 24-inch JWC TL
- David Hill Reservoir
- Key water distribution mains to provide city-wide coverage

The SRP analysis estimates that in its present state, the City's backbone would be operable within 2 weeks to 3 months and the distribution system operable within 3 to 6 months following a CSZ M9 event. See Table 6-1 excerpted from the SRP Figure 29 Existing Estimated Recovery Time.

Table 6-1 | ORP Repair and Recovery Estimates

CSZ M_w 9.0 Event Occurs — CSZ M_w 9.0 Event Occurs — Timeline

ORP Category	CFG Assets	0 - 24 hours	1 - 3 days	3 - 7 days	1 - 2 weeks	2 weeks - 1 month	1 - 3 months	3 - 6 months
Potable water available at supply source (WTP, wells, impoundment)	1. RWTM from Stringtown Bridge to WTP 2. WTP facilities supporting treatment function 3. 24-inch JWC TL	20 - 30% operational	50 - 60% operational		80 - 90% operational	CFG 90% Recovery Time Est. Range		
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational	1. First-tier backbone distribution pipelines 2. 5MG reservoir at WTP	80 - 90% operational			CFG 90% Recovery Time Est. Range			
Water supply to critical facilities available	1. All backbone pipelines 2. David Hill Reservoir	50 - 60% operational	80 - 90% operational			CFG 90% Recovery Time Est. Range		
Water for fire suppression--at key supply points	1. FGFR fire department capability to utlize alternative water sources to suppress fires 2. David Hill Reservoir continued operation 3. 5MG WTP Reservoir continued opration	80 - 90% operational					CFG 90% Recovery Time Est. Range	
Water for fire suppression--at fire hydrants	1. All pipelines required to supply hydrants (most of distribution system)			20 - 30% operational	50 - 60% operational	80 - 90% operational	CFG 90% Recovery Time Est. Range	
Water available at community distribution centers/points	1. Backbone distribution pipelines		50 - 60% operational	80 - 90% operational	CFG 90% Recovery Time Est. Range			
Distribution system operational	1. All transmission and distribution pipelines 2. All pump stations		20 - 30% operational	50 - 60% operational	80 - 90% operational		CFG 90% Recovery Time Est. Range	

6.3 Seismic Hazard Mapping

The most significant seismic hazard to the City is from a major CSZ earthquake. The geologic record shows an average recurrence interval of 500 to 530 years for an M8 or greater earthquake, and an average recurrence interval of about 240 years for smaller (M7 to M8) earthquakes in the CSZ. Recent research predicts a 16 to 22 percent probability of an M8.5 earthquake occurring on the CSZ within the next 50 years (Goldfinger et al., 2016).

In addition to the CSZ, the City may also be impacted from an earthquake on the local Gales Creek fault located approximately 2 miles to the west. The fault runs in a northwesterly direction, parallel to Gales Creek. According to the United States Geological Survey (USGS), the fault can produce an M6.8 earthquake and assign it a recurrence interval of 64,000 years. Research into the frequency of past fault ruptures and the activity of the Gales Creek fault was still underway at the time of the writing of this report. Once a better understanding of the seismic activity of the Gales Creek fault is obtained, its impact on the City's water system should be assessed.

The SRP includes earthquake hazard maps for the City's service area which show peak ground acceleration (PGA), peak ground velocity (PGV), liquefaction susceptibility, permanent ground deformation (PGD) for liquefaction-induced lateral spread, PGD for liquefaction induced settlement, and PGD for seismically-triggered landslides. Maps were developed using both publicly available and project specific data.

6.3.1 Ground Shaking Hazard

Ground shaking potential was estimated from information provided in the ORP and published by the Oregon Department of Geology and Mineral Industries (DOGAMI). Key measures of ground shaking are PGA and PGV. Due to its proximity to the City, PGA estimates for an M6.8 earthquake on the Gales Creek fault are higher but less likely than PGA from a more distant but stronger M9 CSZ event.

6.3.2 Liquefaction Hazard

Liquefaction occurs in loosely deposited saturated granular soils. Such soils, when subjected to earthquake ground shaking that is strong enough or repeated long enough, lose their ability to support structures due to the loss of soil structure and frictional resistance within the soil. Liquefied soil acts like a fluid and can flow resulting in lateral spread deformations and differential settlement. According to the SRP, "PGD from liquefaction is the primary cause of damage to water systems in large earthquakes" (SRP, page 25).

Observations from geologic site reconnaissance and publicly available data including geotechnical borings and reports from prior Oregon Department of Transportation (ODOT), DOGAMI, Oregon Water Resources Investigations, and geotechnical reports provided by the City were used to develop liquefaction susceptibility and PGD maps. Maps provided in the SRP show that the liquefaction hazard within the City is very little to moderate (See SRP Plates 9 and 10) and only

areas along Gales Creek and other streams are susceptible to lateral spread hazard (See SRP Plates 11 and 12).

PGD resulting from liquefaction can be either lateral spreading or settlement. Lateral spreading generally occurs on slopes or riverbanks and ranges between a few inches and several feet. Settlement occurs due to several mechanisms and is more typically on the order of a few inches. According to the SRP, "except for locations along the RWTM and the JWC pipelines, lateral spread hazard in the City is low. The liquefaction-induced settlement estimates are also relatively small (generally less than 3 inches)" (SRP, page 28).

6.3.3 Earthquake-Triggered Landslides

Earthquake-triggered landslides are likely to occur on slopes, particularly in areas of prior landslides. According to the SRP, "the overall risk to the City's infrastructure from seismically-induced landslides is low, except in the Clear Creek watershed area and near the Raw Water Pump Station off Gales Creek Road" (SRP, page 29).

6.4 Seismic Vulnerability Assessment

The SRP included assessment of the seismic vulnerability of the City's water system assets including pipelines, reservoirs, WTP facilities, pump stations, and the public works facility.

6.4.1 Pipelines

Transmission and distribution pipelines required to meet the most critical post-earthquake needs were identified as backbone with the remainder designated as distribution. The backbone system was further prioritized into first tier (high priority lines to key facilities and potential emergency distribution sites) or second tier (connection to the David Hill Reservoir, for instance). Conservative estimates of pipe repairs in an M9 CSZ event were based on seismic hazard mapping and pipeline construction such as pipe material and joint type. Estimated pipeline repairs are shown in Table 6-2. According to the SRP, most repairs are located in liquefaction areas and are clustered in older, cast iron pipes.

Table 6-2 | Summary of Best Estimate All Pipeline Repairs

Table 12: Summary of Best Estimate All Pipeline Repairs (M9 CSZ Earthquake)

Repair Estimates	Backbone System						Non-Backbone Distribution System
	Transmission			Distribution			
	First-Tier	Second-Tier	24-inch JWC TL	First - Tier	Second-Tier	Future	
Median Estimate	2	11	10	29	6	2	213
Upper Estimate[1]	6	32	28	84	17	7	616
Lower Estimate[2]	1	4	3	1	2	1	74

1 - Upper estimate represents median + 1 lognormal standard deviation
2 - Lower estimate represents median - 1 lognormal standard deviation

6.4.2 Reservoirs

Reservoir seismic assessments considered ground shaking, liquefaction-induced lateral spreading and ground settlement, and slope stability. The assessments were based on available existing data. No new geotechnical investigations were performed for this assessment.

The 5 MG WTP Reservoir is "underlain by stiff clean to sandy clays that are not susceptible to liquefaction" (SRP page 40). However, the SRP indicates that the fill slope between the WTP and the reservoir could deform about 2 inches in an M9 CSZ event. A structural assessment of the reservoir identified seismic deficiencies in the roof support columns, central wall, and perimeter walls. The SRP recommends the reservoir be seismically upgraded or replaced.

The David Hill Reservoir is "underlain by stiff silt over siltstone, and is not susceptible to liquefaction" (SRP page 41). Photographs and DOGAMI mapping show recent history of local landslides, particularly in "man-made cuts and over-steepened slopes constructed as part of the road bench above the reservoir" (SRP page 41). The SRP indicates the slope may be unstable, particularly during wet conditions, and could damage piping that cross the deformation zone. A structural assessment of the reservoir shows that the "bending moment capacity of the perimeter walls is exceeded for seismic loading" (SRP page 42). The SRP recommends a more detailed seismic analysis of the David Hill Reservoir, and if analysis indicates vulnerabilities, then the reservoir should be seismically upgraded.

6.4.3 Other Facilities

6.4.3.1 Water Treatment Plant

The SRP findings indicate the WTP site is not susceptible to liquefaction and adjacent slopes are unlikely to be impacted by significant landslide activity in an M9 CSZ event. The WTP buildings were evaluated using ASCE 41-17 standard. The SRP indicates all WTP structures essential for plant operation meet the Immediate Occupancy performance criteria.

6.4.3.2 Pump Stations

The SRP findings show that the pump station sites (David Hill, Watercrest, and Raw Water) do not have a liquefaction or landslides hazard. Minor seismic vulnerabilities were indicated at the David Hill Pump Station including potential cracking near the door in the east wall, but the building meets Immediate Occupancy performance level of ASCE 41-17. No significant seismic vulnerabilities were identified for the Watercrest or Raw Water Pump Stations.

This means that while minor structural and non-structural repairs might be appropriate, these repairs would generally not be required before reoccupancy, and the WTP facilities will be available for continued plant operation.

6.4.3.3 Public Works Facility

The SRP findings indicate the Public Works Facility may be susceptible to liquefaction, with liquefaction-induced PGD of approximately 2 inches. Structures at the site were evaluated independently to assess their seismic vulnerability. According to the SRP, the covered storage structure "could be at risk of significant lateral deformations and structure damage, leading to potential collapse" (SRP page 48). Additionally, the SRP recommends more detailed structural assessment to evaluate the office building and machine shop and the equipment building for the ASCE 41-17 Immediate Occupancy performance level. SRP finds that the supply storage building is expected to meet Immediate Occupancy performance level.

6.4.3.4 10th Avenue Control Station

The SRP findings indicate that the 10th Avenue Control Station site may be susceptible to liquefaction. It is also indicated that while collapse and life safety risk may not be concerns at the structure, a "detailed evaluation of the liquefaction hazard and structural response [should] be performed to meet ASCE41-17 Immediate Occupancy performance level" and that "flexibility be provided to the rigid pipe to wall and pipe to slab penetrations" (SRP page 49).

6.4.3.5 RWTM and Stringtown Bridge

The 16-inch RWTM is suspended by steel rods from the Stringtown Bridge where it crosses Gales Creek. According to the SRP, the bridge piers are likely founded on rock below alluvial soils that are susceptible to liquefaction. The SRP states that "up to 3 feet of liquefaction-induced lateral spreading may occur in an M9 CSZ earthquake" (SRP page 49). The SRP recognizes that while potential cracking of the reinforced concrete may not directly affect the pipelines, liquefaction-induced lateral spread is a seismic risk to the bridge. The Stringtown Bridge was assigned to Group 2B during a 1995 seismic vulnerability study by Washington County. This Group 2B designation means the bridge has three substructure deficiencies. The SRP recommends that the City consider "securing its pipeline either through retrofit of the bridge or separating the pipeline from the bridge and designing the pipeline to withstand liquefaction and ground shaking" (SRP page 49).

6.5 Post-Earthquake Repair

After a seismic event, the City will need to quickly assess the system condition and initiate repairs. If the water system needs repairs, it is likely other critical infrastructure is also damaged. This could mean communication channels are blocked, roadways are damaged so staff and equipment cannot access the system, or City supervisory control and data acquisition (SCADA) infrastructure is damaged and cannot be relied on. The City should develop and practice a post-seismic plan to help facilitate communication, operations, and repairs.

Community partners may be able to assist in an emergency. Oregon Water/Wastewater Agency Response Network (ORWARN) is a network of water and sewer agencies that provide voluntary assistance to each other during an emergency. It is anticipated that after a CSZ event other local

providers will likely also be dealing with an immediate emergency and thus unable to assist. The SRP recommends looking into the interstate Emergency Management Assistance Compact (EMAC) at the state level for more widespread assistance.

Assuming the City has adequate staff and access to begin repairs, the SRP estimates that repairs can take anywhere from a few hours for pipes less than 12 inches in diameter, to more than a day for larger pipes. When applying this repair time to over 20 median estimated repairs in the backbone and significantly larger number of repairs in the distribution system the timeline to return to normal operations quickly balloons to days or weeks. To help facilitate this, the SRP recommends the City establish a post-earthquake pipeline repair protocol (SRP, page 52).

The suggested repair protocol may include steps for pipe material acquisition and additional resources. The City owns an array of repair equipment including "one backhoe, one excavator, two hydro-excavators, and one water service pickup truck to support the hydro-excavator" (SRP, page 50). The SRP found that "at present, the City does not have sufficient stockpile to repair all of the estimated pipeline damage" (SRP, page 50). Stockpiling all possibly needed materials is impractical due to "space restrictions and damage/deformation that can occur over time" (SRP, page 51). These challenges should be weighed with the likely challenges in supply chain following a seismic event due to high demand, disruptions in transportation or production, and time.

6.6 Mitigation Options and Recommendations

According to the SRP, the overall seismic risk is moderate, yet the risk of service interruption is high. If a CSZ earthquake were to strike today, the SRP estimates that it would take between three and six months to return to 90 percent of normal operations, assuming the damage to 5 MG Reservoir does not result in the uncontrolled release of stored water. If the damage to the 5 MG Reservoir is catastrophic, the repair time will increase significantly. The three to six month time frame is more than the ORP suggested timeframe of two weeks to one month to restore operations to 90 percent of all the ORP categories listed in Table 6-1.

Improving the seismic resilience of the entire system can be cost and time prohibitive, so the SRP focused on an approach to reduce costs and at the same time achieve as many of the critical ORP goals as possible. The SRP provides two packages of mitigation options, a lower cost Option 1 designed to achieve ORP goals for the first-tier backbone and critical water supply elements and a higher cost Option 2, which is an extension of Option 1 by including upgrades for most vulnerable elements of the second-tier backbone to provide additional redundancy. The SRP recognizes that neither option will fully satisfy all the ORP goals but these upgrades, coupled with careful emergency operations planning, will significantly improve the resiliency of the City's water system.

The SRP presents a cost-effective solution to improve recovery by targeting the most vulnerable pipe materials and highest hazard areas. These recommendations will improve the likelihood that water is available for emergency use and firefighting immediately following the earthquake and reduce the time to restore the non-backbone water distribution system so water is available for daily use and economic activity.

This WSMP CIP includes recommendations from Option 1 and Option 2 of the SRP as planned improvements that can be performed using a two-phase approach. Phase 1 of the improvements are the same as SRP's Option 1 and focus on the first-tier backbone pipelines and infrastructure so that 80 to 90 percent of the first-tier backbone system is operable within 24 hours. Phase 2 includes the additional recommended improvements included in the SRP's Option 2 and addresses upgrades to the second-tier backbone system by replacing 15.5 miles of cast iron pipeline. Phase 2 improvements will meet all the ORP Goals to be 80 to 90 percent operational, except for goals related to the non-backbone water distribution system. To meet all the water system goals of the ORP, an additional 25.1 miles of existing ductile iron pipe would have to be replaced with seismically resistant pipe, which is likely cost prohibitive. The recommended phased approach will achieve many, but not all, of the ORP water system goals and when coupled with emergency operations planning will significantly improve the City's water system seismic resiliency.

6.6.1 Phase 1 Mitigation

The SRP recommends the City take the following steps to address Backbone vulnerabilities.

- Portable or permanent emergency pumping equipment to withdraw water from Gales Creek at Stringtown Bridge including backup power
- Geotechnical study to identify sections of the RWTM from Stringtown Road Bridge to the WTP
- Seismic upgrades of the RWTM between Stringtown Road Bridge and WTP based on the results of the Geotechnical Study. This could include approximately 1.2 miles of pipe susceptible to liquefaction and approximately 500 feet within Forest Glen Park to avoid a historic landslide area
- Backup power to existing Raw Water Pump Station
- Seismic upgrade/replace 5 MG Reservoir at City WTP site
- Assess and upgrade, if needed, anchorage of emergency generator electrical cabinets.
- Replace 4 miles cast iron pipes in the first-tier backbone with seismically resilient pipe.
- Detailed structural analysis of the Public Works Office Building to assess Life Safety performance criteria and to assess mechanical equipment and electrical panel anchorage
- Install isolation valves along backbone.

6.6.2 Phase 2 Mitigation

Once the Phase 1 mitigations are complete, Phase 2 includes the following improvements to further increase the resiliency of the water system.

- Replace 0.8 miles cast iron pipe within the second-tier backbone with seismically resilient pipe.
- Geotechnical study to identify sections of the RWTM from Clear Creek Watershed to the Stringtown Road Bridge
- Replace RWTM from Watershed to Stringtown Road Bridge, based on the findings of the Geotechnical study. This could include approximately 1.9 miles of pipeline from Clear Creek to the Gales Creek Cemetery and approximately 3.7 miles of pipeline between the Gales Creek Cemetery and the Stringtown Road Bridge.
- Detailed structural study of the existing Stringtown Road Bridge (County owned asset) and alternative analysis comparing the seismic improvement costs for the Stringtown Road Bridge and alternative methods evaluation for the RWTM to cross Gales Creek. Then modify the RWTM crossing of Gales Creek based on the findings of the alternatives analysis.
- Replace 1.3 miles of the 24-inch JWC TL with seismic resistant pipe including pipeline flexibility at 10th Avenue Control Station building penetrations. Perform geotechnical investigations to potentially reduce the replacement length.
- Detailed evaluation of liquefaction hazard and structural response of the 10th Avenue Control Station and perform as-needed improvements to meet ASCE 41-17's Immediate Occupancy performance objectives.
- Backup power added to the David Hill Pump Stations
- Seismic assessment at David Hill Reservoir
- Replace 15.5 miles cast iron pipe in the non-backbone distribution system.
- Isolation valves should be added throughout the system to help isolate leaks and pipeline failures post seismic event.

6.6.3 Additional Actions

The SRP also recommended the following additional action items to address system and operational deficiencies.

- Develop a long-term pipeline replacement program for non-cast iron pipelines that prioritize mains in terms of liquefaction severity, age, and corrosion.

- Stockpile repair resources for 10 workdays worth of repairs.
- Establish material procurement protocols and on-call contracts with suppliers.
- Develop repair protocols for rapid reimbursement from FEMA.
- Develop EMAC with State of Oregon for mutual aid from other states.
- Emergency response training and protocols
- Programs to evaluate and test emergency response equipment
- Develop and maintain utility maps with locations of pipeline repairs.

6.7 Summary

The SRP concluded that while seismic risk in the event of a CSZ M9 event in the City is moderate, the risk of service interruption is high. The RWTM supplying the City's WTP is at risk, particularly due to landslide along the river valley. City facilities will likely be affected to various degrees. Pipelines, particularly aging cast iron pipes, are at high risk of failure. To address these deficiencies, system improvements should be made, first addressing the first-tier backbone and then the rest of the system.

Section 7

Section 7

Capital Improvement Program

This section presents recommended improvements for the City's water system based on the analysis and findings presented in Section 4, Section 5, and Section 6, and projects identified in the City's current water CIP projects list. The CIP presented in Table 7-1 summarizes recommended improvements and provides an approximate timeframe for each project. Proposed improvements are illustrated in Figure 7-1, and individual project sheets are included in Appendix I.

7.1 Project Cost Estimates

An estimated project cost has been developed for each recommended improvement consistent with previously identified projects from the City's current CIP and current preliminary design work, as applicable. Cost estimates represent opinions of cost only, acknowledging that final costs of individual projects will vary depending on actual labor and material costs, market conditions for construction, regulatory factors, final project scope, project schedule and other factors. The Association for the Advancement of Cost Engineering International (AACE) classifies cost estimates depending on project definition, end usage and other factors. The cost estimates presented here are considered Class 5 with an end use being a study or feasibility evaluation and an expected accuracy range of -50 percent to +100 percent. As the project is better defined, the accuracy level of the estimates can be narrowed.

Since construction costs change periodically, an indexing method to adjust present estimates in the future is useful. The Engineering News-Record (ENR) Construction Cost Index (CCI) is a commonly used index for this purpose. For purposes of future cost estimate updating; the current ENR CCI for Seattle, Washington is 13,165 (June 2021).

7.2 Timeframes

A summary of all improvement projects and estimated project costs is presented in Table 7-1. This CIP table provides for project sequencing by showing prioritized projects for the following timeframes.

- 0 to 5-year timeframe - recommended completion through 2027
- 6 to 10-year timeframe - recommended completion between 2027 and 2032
- 11 to 20-year timeframe - recommended completion between 2033 and 2042
- 20+ year timeframe – recommended completion after 2042

Table 7-2 provides a detailed yearly breakdown of the first five years of the CIP.

7.3 Supply

7.3.1 City Supply Projects

The City will need to consider additional supply within the near future. To address these concerns, several projects are included in the CIP.

- The City needs to complete a Water Supply Study to make an informed decision on the best long-term supply strategy and fill the remaining information gaps. As part of this analysis, the need for and timing of projects related to supply will be confirmed. The City should complete a facility assessment at the City WTP to understand upgrades, replacements, and limitations of future service. This will be valuable for performing cost/benefit analyses of supply alternatives that include the City WTP.

- No matter which alternative is selected, the City should develop reliable and resilient transmission for their full JWC treatment ownership. In the short term, this means pursuing leasing rights from the City of Hillsboro in the existing 24-inch JWC TL greater than the existing 6.1 MGD ownership. Long term, the City should replace the 24-inch JWC TL with seismically resilient transmission. This transmission line should be sized for future needs, including the potential for increased JWC treatment capacity. This project is included under Seismic Improvements Phase 2 (E2-5) but phased for the next 0-5 years.

- The City also will likely need to plan for implementing the Barney Reservoir capacity buyback from TVWD within 50 years, depending on future reservoir operations, drought conditions, and demands. The request process can take four years to complete.

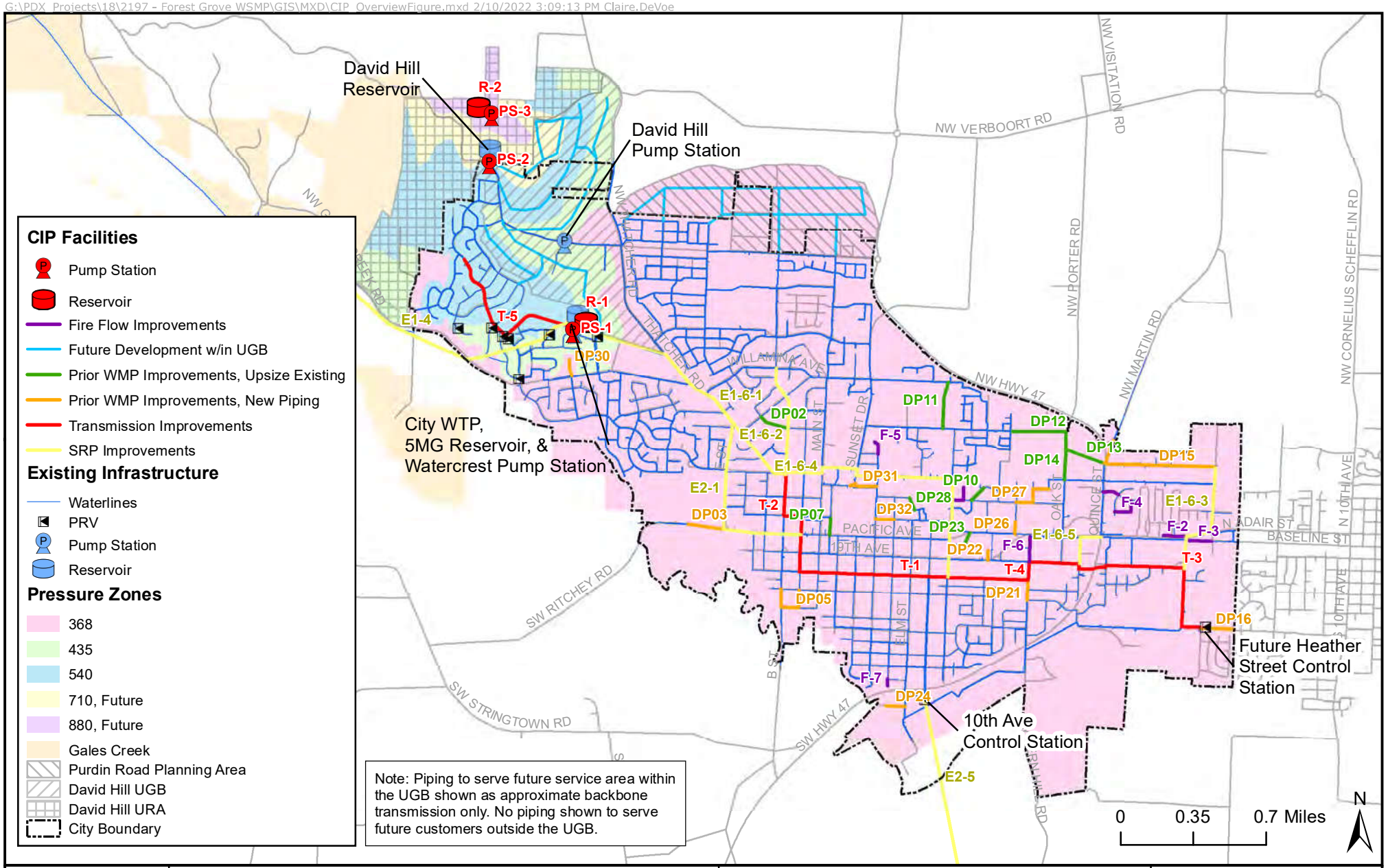
- A streamflow gauging station is required on Gales Creek as a condition of T-11677 to transfer the POD from Gales Creek to Springhill Pump Station, if taking water from June 1 to September 30.

7.3.2 Joint Water Commission (JWC)

To maintain the City's primary supply from the JWC, on-going investment is needed. The JWC partners are currently planning on the following investments.

- Various JWC on-going shared-cost upgrade and replacement projects including seismic mitigation at the existing WTP, on-site electrical, building, and security capital maintenance, as well as asset management

- JWC WTP upgrades to be completed in 2023 to realize full capacity of the WTP



murraysmith

City of Forest Grove
Water System Master Plan

Figure 7-1
CIP Improvements

FOREST GROVE OR

- Seismic retrofit to the existing Scoggins Dam, which provides raw water storage in Hagg Lake from Scoggins Creek to supply the JWC WTP during low summer flows in the Tualatin River. The United States Bureau of Reclamation owns the dam and is pursuing funding under the federal Safety of Dams program. Additional funding would be split between the repayment partners including the Cities of Hillsboro, Beaverton, and Forest Grove, Clean Water Services (CWS), and TVID.

7.4 Storage Reservoirs

As presented in Section 5, the City will need additional storage at all levels within 20 years. The age and condition of the City's primary storage facility (the 5 MG Reservoir at the City WTP) requires replacement soon.

7.4.1 Two 5 MG Reservoirs at the Existing City WTP Site

The existing 5 MG Reservoir located at the City's WTP site is failing, does not meet seismic standards, and needs to be replaced. Two 5 MG Reservoirs are proposed to replace the 5 MG Reservoir onsite, with phased construction to allow for continued operations and development timing of the second reservoir (likely within the next 10 years, see Figure 5-1 for one example of construction phasing – may not represent actual time needed for demolition and construction, to be reviewed during pre-design).

7.4.2 710 Reservoir

A 710 reservoir is proposed to serve future customers located above existing service elevations. The construction of the single, 0.5 MG reservoir can be phased with development. Temporary service to customers prior to reservoir construction can be achieved via a closed zone pump station, described further below. This reservoir size should be verified in design when development occurs.

7.5 Pump Stations

7.5.1 Upgrade Watercrest Pump Station

Although the pumping capacity analysis in Table 5-8 indicates a capacity deficiency in existing stations after the 20-year planning horizon, it is recommended the City plan for upgrading existing pumping to the upper zones. This could occur through improvements to either the Watercrest PS or the David Hill PS. Costs shown in the CIP assume upsizing of the Watercrest PS. This station will operate more with additional demand at the top of the hill. In addition to station upgrades, transmission upgrades may also be required to accommodate increased flows.

7.5.2 New 710 Pump Station

A constant pressure 710 PS is recommended to be constructed with development of the upper zone. Once the 710 reservoir is built, this station can transition to pumping to storage, and no longer needs to provide fire flow capacity.

7.5.3 New 880 Pump Station

It was assumed areas above the proposed 710 pressure zone would develop once the 710 reservoir is constructed. To serve these customers, a new 880 closed zone PS should be constructed, similar to how the 710 PS will operate prior to construction of the 710 reservoir. Suction supply is assumed from the 710 reservoir, as it is not recommended to operate two closed zone pump stations in series.

7.6 Distribution Mains

7.6.1 Fire Flow Improvements

The City has known fire flow limitations in the industrial area in the northeast of town. The Heather Street Control Station and upsized transmission to the Heather Street Control Station and the 10th Avenue Control Station will mitigate many of these deficiencies. Limited improvements are recommended throughout the rest of the system to address fire flow deficiencies.

7.6.2 Transmission Improvements

Three transmission improvement projects are recommended.

- *10th Avenue Transmission*: improves WTP reservoir filling, fire flow transmission, and supply from Heather Avenue
- *Heather Avenue Transmission*: potential limitations for railroad and highway crossings, important if the City anticipates regular use of the Heather Street Control Station
- *Upper Zone Transmission from Watercrest PS* – existing 8-inch diameter main, this is a critical upsizing improvement for future supply to zones above existing 540 and tank filling from the Watercrest PS. If the David Hill PS is improved instead of the Watercrest PS, this improvement will not be required.

7.6.3 Piping Improvements Identified in the Prior WSMP

Piping improvements to address system looping and upsize existing piping were included from the prior WSMP. Construction of these projects is assumed to occur as required system looping to support local development or as opportunities arise to pair piping improvements with other utility projects.

7.7 Seismic Improvements

Overlapping sections of piping improvements suggested in both the SRP and other CIP projects (transmission improvements along 18th Ave, for example) were trimmed from the SRP projects so as not to double count.

7.7.1 Phase I

Phase I improvements were identified in the SRP and are intended to meet the ORP goal of 80 to 90 percent of the backbone operational within 24-hours of a seismic event. See Section 6.6.1 for additional information. These projects are recommended to be completed within 0-5 years.

7.7.2 Phase II

Phase II improvements were identified in the SRP and are intended to meet the ORP goal of 80 to 90 percent of the entire system operational, except for goals related to the non-backbone water distribution system. To meet all the water system goals of the ORP, an additional 25.1 miles of existing ductile iron pipe would have to be replaced with seismically resistant pipe, which is likely cost prohibitive. The recommended phased approach will achieve many, but not all, or the ORP water system goals and when coupled with emergency operations planning, will significantly improve the City's water system seismic resiliency. See Section 6.6.2 for additional information. Projects are recommended to be completed within 11-20 years, except for improvements to the JWC TL which is recommended for 0-5 years and discussed in the supply section.

7.7.3 Additional Actions

Additional recommended actions were identified in the SRP to mitigate seismic risk. See Section 6.6.3 for additional description. These projects are generally either smaller projects or actions identified for the City to complete to aid in post disaster operations and planning. Projects are recommended to be completed within 0-5 years.

7.8 Planning Studies

7.8.1 System-wide Planning

The City will complete a rate study once this WSMP has been adopted. It is also recommended that the City continue to update the WSMP and Water Management and Conservation Plan (WMCP) every 10 years. An updated WSMP is required by the State of Oregon for a 20-year planning period. However, with potential changes to the City supply depending on findings of the WTP analysis and ongoing expansion of the City service area, it is prudent for the City to continue to regularly evaluate capital investment and prioritize needs for the water system and document this long-term water service strategy in the WSMP.

7.8.2 Emergency Water Supply Study

It is recommended the City complete an emergency water supply study to identify potential local sources of emergency water supply and develop a plan to implement development of, or access to, emergency water supply sources to mitigate for potential disruption of the City's primary water supplies in a regional emergency.

7.8.3 Develop New Engineering Standards

The City should consider updating the engineering standards to meet current seismic and resiliency criteria.

7.9 CIP Funding

The City may fund the water system CIP from a variety of sources, including governmental grant and loan programs, publicly issued debt, and cash resources and revenue. The City's cash resources and revenue available for water system capital projects include water rate funding, cash reserves, and system development charges (SDCs).

Generated through development and system growth, SDCs are typically used by utilities to support capital funding needs. The charge is intended to recover a fair share of the costs of existing and planned facilities that provide capacity to serve new growth.

As shown in Table 7-1, the City's proposed CIP includes significant investment, particularly in supply and storage improvements. This new capacity will serve growth while also providing more resilient water facilities that benefit all customers. An evaluation of water rates and SDCs in support of the water system CIP will be completed as follow-on work to this WSMP.

Table 7-1 | Capital Improvement Plan Summary

Improvement Category	Project No.	Project Title	CIP Cost Summary[1]					Purpose
			5-year 2022 to 2027	5 to 10-year 2028 to 2032	10 to 20-year 2033 to 2042	20-year +	20-year TOTAL	
Supply	S-1	Streamflow gauging station - Gales Creek	$75,000				$75,000	Requirement
	S-2	Barney Reservoir raw water capacity "buy-back" from TVWD				$36,400,000		Growth, Reliability
	S-3	Long Term Water Supply Study and City WTP Facility Plan	$400,000				$400,000	
	JWC Supply Projects - Forest Grove share							
	S-4	JWC capital repair and replacement	$1,100,000				$1,100,000	Reliability
	S-5	Expansion projects - cathodic protection, Spring Hill Pumping Plant mitigation, disinfection facility, land purchase	$900,000				$900,000	Growth
	S-6	Minor capital projects - meters, equipment, building improvements	$120,000				$120,000	Reliability
	S-7	Scoggins seismic retrofit			$2,040,000	$8,160,000	$2,040,000	Resilience
	S-8	WTP long-term seismic improvements			$5,600,000		$5,600,000	Resilience
		Supply Subtotal	**$2,595,000**	**$-**	**$7,640,000**	**$44,560,000**	**$10,235,000**	
Storage Reservoirs	R-1	Replace existing 5 MG Reservoir at City WTP with two 5 MG Reservoirs (10 MG total)	$11,300,000	$11,300,000			$22,600,000	Capacity, resilience, growth
	R-2	710 Reservoir (0.5 MG)			$1,000,000		$1,000,000	Growth
		Storage Subtotal	**$11,300,000**	**$11,300,000**	**$1,000,000**	**$-**	**$23,600,000**	
Pump Stations	PS-1	Upgrade Watercrest Pump Station	$1,200,000				$1,200,000	Reliability
	PS-2	710 constant pressure Pump Station	$900,000				$900,000	Growth
	PS-3	880 constant pressure Pump Station			$850,000		$850,000	Growth
		Pump Stations Subtotal	**$2,100,000**	**$-**	**$850,000**	**$-**	**$2,950,000**	
Piping Improvements	*Fire Flow Improvements*							
	F-1	Multifamily Residential - 22nd Ave - Garden Grove Apartments			$260,000		$260,000	Fire Flow
	F-2	Commercial - Pacific Ave - Best Western			$260,000		$260,000	Fire Flow
	F-3	Commercial - Pacific Ave - Mountain View Ln to Yew St			$520,000		$520,000	Fire Flow
	F-4	Residential – 23rd Ave			$350,000		$350,000	Fire Flow
	F-5	Residential - Cedar St			$90,000		$90,000	Fire Flow
	F-6	Industrial - Maple St			$250,000		$250,000	Fire Flow
	F-7	Residential - Douglas St			$40,000		$40,000	Fire Flow
	HDR Improvements - New Pipes							
	HDR_DP02	Harvey Clarke Elementary			$220,000		$220,000	HDR New Pipes
	HDR_DP07	College Way connection from Pacific Ave			$130,000		$130,000	HDR New Pipes
	HDR_DP10	Bard Park connection			$130,000		$130,000	HDR New Pipes
	HDR_DP11	Firwood Ln			$350,000		$350,000	HDR New Pipes
	HDR_DP12	Oak St to Kingwood St connection			$650,000		$650,000	HDR New Pipes
	HDR_DP13	Oak St to Nehalem Hwy connection			$460,000		$460,000	HDR New Pipes
	HDR_DP14	Oak St to RR connection			$240,000		$240,000	HDR New Pipes
	HDR_DP23	19th Pl to Pacific Ave connector near Les Schwab			$110,000		$110,000	HDR New Pipes
	HDR_DP28	RR crossing from Green Ct to 22nd Ave			$130,000		$130,000	HDR New Pipes
	HDR Improvements - Upsize Existing Pipes							
	HDR_DP03	Tom McCall Upper Elementary			$390,000		$390,000	HDR Upsize

Improvement Category	Project No.	Project Title	CIP Cost Summary[1]					Purpose
			5-year 2022 to 2027	5 to 10-year 2028 to 2032	10 to 20-year 2033 to 2042	20-year +	20-year TOTAL	
	HDR_DP05	B St and 16th Ave			$350,000		$350,000	HDR Upsize
	HDR_DP06	A St between 16th and 17th Ave			$150,000		$150,000	HDR Upsize
	HDR_DP15	24th Ave east from Nehalem Hwy			$1,210,000		$1,210,000	HDR Upsize
	HDR_DP16	Heather St east			$390,000		$390,000	HDR Upsize
	HDR_DP17	NW Martin Rd connector			$290,000		$290,000	HDR Upsize
	HDR_DP21	Maple St from 17th Ave to 18th Ave			$200,000		$200,000	HDR Upsize
	HDR_DP22	19th Ave Safeway			$80,000		$80,000	HDR Upsize
	HDR_DP24	9th Ave from Elm St			$180,000		$180,000	HDR Upsize
	HDR_DP26	Laurel St north from Pacific Ave			$100,000		$100,000	HDR Upsize
	HDR_DP27	22nd Ave, Maple St, and 22nd Pl			$350,000		$350,000	HDR Upsize
	HDR_DP30	Buxton Ct			$130,000		$130,000	HDR Upsize
	HDR_DP31	University Ave from Cedar St to Sunset Dr			$230,000		$230,000	HDR Upsize
	HDR_DP32	21st Ave from Douglas St to Cedar St			$150,000		$150,000	HDR Upsize
	Transmission Improvements							
	T-1	10th Ave Transmission, upsize existing 12" transmission from 18th and Filbert St to 23rd and B St, 20"	$3,050,000				$3,050,000	Transmission
	T-2	10th Ave Transmission, upsize existing 16" from 23rd and B St to Pacific Ave and A St, 20"		$1,440,000			$1,440,000	Transmission
	T-3	Heather Ave Transmission, upsize existing 8-10" from Heather Ave Intertie, north to 19th Ave, to TV Hwy crossing, 20"	$2,880,000				$2,880,000	Transmission
	T-4	Heather Ave Transmission, upsize existing 8" from east of TV Hwy, TV Hwy crossing, to Filbert and 18th Ave, 20"		$3,600,000			$3,600,000	Transmission
	T-5	Transmission from Watercrest Pump Station to Hillside Way along Forest Gale Dr	$1,910,000				$1,910,000	Transmission
		Distribution Mains Subtotal	**$7,840,000**	**$5,040,000**	**$8,210,000**	**$-**	**$21,090,000**	
Seismic Improvements	*Phase I Improvements*							
	E1-1	Portable pumping equipment for use at Stringtown Bridge	$875,000				$875,000	Resilience
	E1-2	Raw water pump backup power supply	$200,000				$200,000	Resilience
	E1-3	Geotechnical study to identify RWTM vulnerabilities between Stringtown Road Bridge and WTP (Section 1)	$100,000				$100,000	Resilience
	E1-4	Seismic upgrade of the RWTM (Section 1)	$3,940,000				$3,940,000	Resilience
	E1-5	Assess and upgrade anchorage of emergency generator electrical cabinets	$25,000				$25,000	Resilience
	E1-6-1	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe from City WTP to B St (20")	$5,040,000				$5,040,000	Resilience
	E1-6-2	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe along B St to Forest Grove HS (upsize to 8" minimum)	$820,000				$820,000	Resilience
	E1-6-3	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe looping north around Pacific University (10-12")	$1,340,000				$1,340,000	Resilience
	E1-6-4	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe along Poplar St and Pacific Ave to loop to industrial center (8" minimum)	$2,050,000				$2,050,000	Resilience
	E1-6-5	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe along Mountainview Ln and Yew St to industrial center (8-10" minimum)	$430,000				$430,000	Resilience

Improvement Category	Project No.	Project Title	CIP Cost Summary[1] 5-year 2022 to 2027	5 to 10-year 2028 to 2032	10 to 20-year 2033 to 2042	20-year +	20-year TOTAL	Purpose
	E1-7	Structural analysis of Public Works Office Building to assess life safety performance and mechanical equipment/electrical panel anchorage	$100,000				$100,000	Resilience
	E1-8	Install isolation valves along backbone	$1,000,000				$1,000,000	Resilience
	Phase II Improvements							
	E2-1	Replace 4,600 lf of 8-10" cast iron pipe in Tier 2 backbone with seismically resilient pipe			$1,500,000		$1,500,000	Resilience
	E2-2	Geotechnical study to identify RWTM vulnerabilities between Clear Creek Watershed and Stringtown Road Bridge (Section 2)			$100,000		$100,000	Resilience
	E2-3	Seismic upgrade of the RWTM (Section 2)				$17,040,000	$-	Resilience
	E2-4	Detailed structural study of Stringtown Road Bridge and alternatives analysis for RWTM crossing of Gales Creek			$150,000		$150,000	Resilience
	E2-5	Replace 1.3 miles of existing 24-inch JWC TL with seismic resistant pipe, including 10th Ave Control Station building penetrations	$5,940,000				$5,940,000	Resilience
	E2-6	Detailed seismic structural analysis on 10th Avenue Control Station and required improvements			$50,000		$50,000	Resilience
	E2-7	Backup power added to David Hill Pump Stations			$125,000		$125,000	Resilience
	E2-8	Seismic analysis of David Hill Reservoir			$75,000		$75,000	Resilience
	E2-9	Replace 15.5 miles of cast iron pipe in distribution system				$23,570,000	$-	Resilience
	E2-10	Install isolation valves throughout the system			$2,000,000		$2,000,000	Resilience
	Additional Improvements							
	E3-1	Develop long term pipeline improvement program	$25,000				$25,000	Resilience
	E3-2	Stockpile repair resources for 10 workdays of repairs	$50,000				$50,000	Resilience
	E3-3	Establish material procurement protocols and on-call contracts with suppliers	$5,000				$5,000	Resilience
	E3-4	Develop repair protocols for rapid reimbursement from the Federal Emergency Management Agency (FEMA).	$5,000				$5,000	Resilience
	E3-5	Develop emergency management assistance compact (EMAC) with OR for mutual aid from other states.	$2,500				$2,500	Resilience
	E3-6	Emergency response training and protocols.	$40,000				$40,000	Resilience
	E3-7	Programs to evaluate and test emergency response equipment.	$10,000				$10,000	Resilience
	E3-8	Develop and maintain utility maps with locations of pipeline repairs.	$50,000	$50,000	$100,000		$200,000	Resilience
		Seismic Subtotal	**$22,047,500**	**$50,000**	**$4,100,000**	**$40,610,000**	**$26,197,500**	
Planning	PL-1	Water Management & Conservation Plan update		$100,000			$100,000	Requirement
	PL-2	Water Master Plan update			$300,000		$300,000	Requirement
	PL-3	Emergency Water Supply Study		$150,000			$150,000	Resilience
	PL-4	Develop new engineering standards		$50,000			$50,000	Resilience
	PL-5	Complete Rate Study after WSMP adoption	$50,000				$50,000	Requirement
		Planning Subtotal	**$50,000**	**$300,000**	**$300,000**	**$-**	**$650,000**	
		CIP Total	**$45,932,500**	**$16,690,000**	**$22,100,000**	**$85,170,000**	**$84,722,500**	

Table 7-2 | 0-5 Year Capital Improvement Plan Prioritization

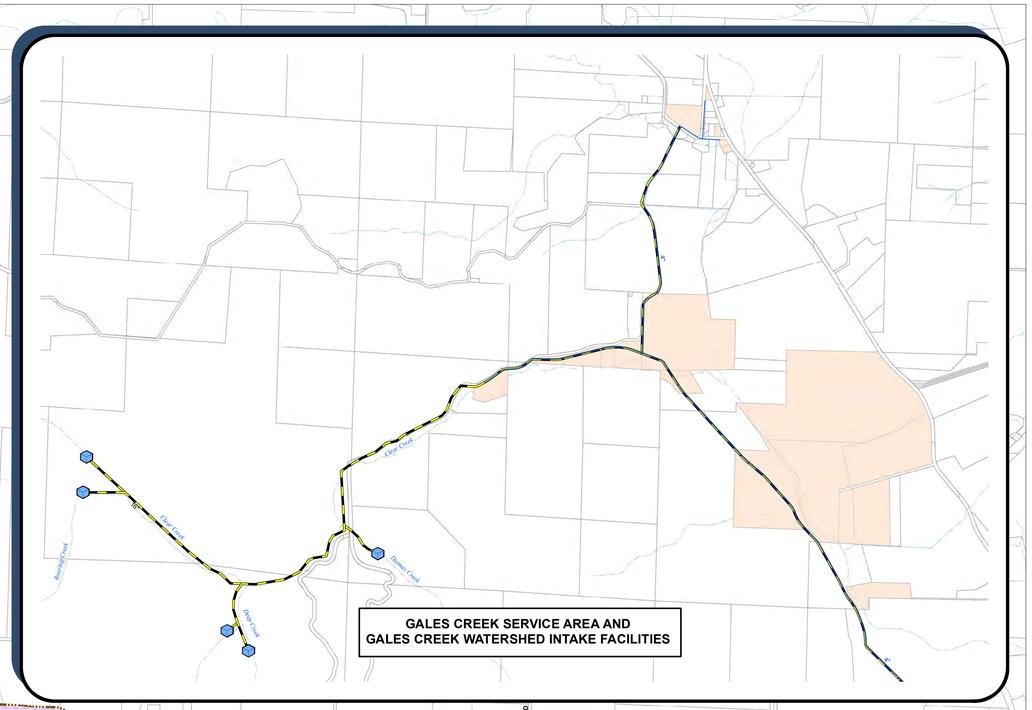
Category	Project No.	Project Title	Total Cost	FY22-23	FY23-24	FY24-25	FY25-26	FY26-27
Supply	S-1	Streamflow gauging station - Gales Creek	$75,000	$75,000				
	S-3	Long Term Water Supply Study and City WTP Facility Plan	$400,000	$400,000				
	S-4	JWC capital repair and replacement	$1,100,000			$1,100,000		
	S-5	Expansion projects - cathodic protection, Spring Hill Pumping Plant mitigation, disinfection facility, land purchase	$900,000	$180,000	$180,000	$180,000	$180,000	$180,000
	S-6	Minor capital projects - meters, equipment, building improvements	$120,000	$24,000	$24,000	$24,000	$24,000	$24,000
Storage	R-1	Replace existing 5 MG Reservoir at City WTP with two 5 MG Reservoirs (10 MG total, 5MG in 0-5 yr)	$11,300,000	$2,825,000	$8,475,000			
Pump Stations	PS-1	Upgrade Watercrest Pump Station	$1,200,000		$300,000	$900,000		
	PS-2	710 constant pressure Pump Station	$900,000			$225,000	$675,000	
Piping	T-1	10th Ave Transmission, upsize existing 12" transmission from 18th and Filbert St to 23rd and B St, 20"	$3,050,000	$1,525,000	$1,525,000			
	T-3	Heather Ave Transmission, upsize existing 8-10" from Heather Ave Intertie, north to 19th Ave, to TV Hwy crossing, 20"	$2,880,000		$1,440,000	$1,440,000		
	T-5	Transmission from Watercrest Pump Station to Hillside Way along Forest Gale Dr	$1,910,000			$955,000	$955,000	
Seismic	E1-1	Portable pumping equipment for use at Stringtown Bridge	$875,000	$875,000				
	E1-2	Raw water pump backup power supply	$200,000		$200,000			
	E1-3	Geotechnical study to identify RWTM vulnerabilities between Stringtown Road Bridge and WTP (Section 1)	$100,000		$100,000			
	E1-4	Seismic upgrade of the RWTM (Section 1)	$3,940,000				$1,970,000	$1,970,000
	E1-5	Assess and upgrade anchorage of emergency generator electrical cabinets	$25,000			$25,000		
	E1-6-1	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe from City WTP to B St (20")	$5,040,000	$1,008,000	$1,008,000	$1,008,000	$1,008,000	$1,008,000
	E1-6-2	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe along B St to Forest Grove HS (upsize to 8" minimum)	$820,000		$820,000			
	E1-6-3	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe looping north around Pacific University (10-12")	$1,340,000	$268,000	$268,000	$268,000	$268,000	$268,000
	E1-6-4	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe along Poplar St and Pacific Ave to loop to industrial center (8" minimum)	$2,050,000		$512,500	$1,025,000	$512,500	
	E1-6-5	Replace Tier 1 backbone cast iron pipe with seismically resilient pipe along Mountainview Ln and Yew St to industrial center (8-10" minimum)	$430,000				$430,000	
	E1-7	Structural analysis of Public Works Office Building to assess life safety performance and mechanical equipment/electrical panel anchorage	$100,000	$20,000	$20,000	$20,000	$20,000	$20,000
	E1-8	Install isolation valves along backbone	$1,000,000	$200,000	$200,000	$200,000	$200,000	$200,000
	E2-5	Replace 1.3 miles of existing 24-inch JWC TL with seismic resistant pipe, including 10th Ave Control Station building penetrations	$5,940,000	$1,485,000	$4,455,000			
	E3-1	Develop long term pipeline improvement program	$25,000					$25,000
	E3-2	Stockpile repair resources for 10 workdays of repairs	$50,000					$50,000
	E3-3	Establish material procurement protocols and on-call contracts with suppliers	$5,000	$5,000				
	E3-4	Develop repair protocols for rapid reimbursement from the Federal Emergency Management Agency (FEMA).	$5,000	$5,000				
	E3-5	Develop emergency management assistance compact (EMAC) with OR for mutual aid from other states.	$2,500	$2,500				
	E3-6	Emergency response training and protocols.	$40,000	$40,000				
	E3-7	Programs to evaluate and test emergency response equipment.	$10,000	$10,000				
	E3-8	Develop and maintain utility maps with locations of pipeline repairs.	$50,000	$50,000				
Planning	PL-5	Complete Rate Study after WSMP adoption	$50,000	$50,000				
		0-5 Year CIP Totals	**$45,932,500**	**$9,047,500**	**$19,527,500**	**$7,370,000**	**$6,242,500**	**$3,745,000**

Appendix

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APPENDIX A
PLATE 1: WATER SYSTEM MAP

SEE INSET FOR
GALES CREEK SERVICE AREA
AND INTAKE FACILITIES



NW HILLSIDE RD
NW KANSAS CITY RD
NW GALES CREEK RD
NW STRINGTOWN RD
David Hill
Pump Station
David Hill
Reservoir
NW THATCHER RD
DAVID HILL
PLANNING AREA
PURDIN ROAD
PLANNING AREA
NW HWY 47
NW PORTER RD
City
WTP
5 MG
Reservoir
Watercrest
Pump Station
Raw Water Booster
Pump Station
NW GALES CREEK RD
GALES CREEK RD
THATCHER RD
WILLAMINA AVE
SUNSET DR
MAIN ST
OAKES CREEK RD
NW MARTIN RD
NW CORNELIUS SCHEFFLIN RD
CITY OF
FOREST GROVE
CITY OF
CORNELIUS
N ADAIR ST
BASELINE ST
N 10TH AVE
S 10TH AVE
N 19TH AVE
E ST
B ST
PACIFIC AVE
19TH AVE
19TH WAY
MAPLE DR
OAK ST
QUINCE ST
LINCOLN ST
SW HWY 47
Future Heather Intertie to
JWC 72-inch NTL
10th Avenue Control Station
(Supply from 24-inch JWC TL)
SW FERN HILL RD
Tualatin River
SW RITCHEY RD
SW STRINGTOWN RD
SW GALLEY RD

N

Legend

- Existing Reservoir
- Existing Pump Station
- Water Treatment Plant
- PRV
- Intertie
- Intake Facility
- Existing Raw Water Transmission
- Existing Water Main
- Urban Growth Boundary (UGB)
- City Limits
- Railroad

Pressure Zones

- 368
- 435
- 540
- 710, Future
- 880, Future
- GalesCreek

Planning Areas:

- David Hill UGB
- Purdin Road Planning Area
- David Hill URA

PLATE 1

FOREST GROVE OREGON

City of Forest Grove
Water System Master Plan

Existing Water System Map

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February 2019 18-2197

APPENDIX B
FOREST GROVE AND DILLEY PRV FLOW TEST, JWC, 2019

MEMORANDUM

To: Kevin Hanway, General Manager

From: Nesh Mucibabic, Principal Engineer

Date: May 6, 2019

Re: Uncounted flows along 24-inch transmission main between JWC Plant and delivery points at the City of Hillsboro Dilley and Forest Grove pressure reducing valve (PRV) facilities.

1. Introduction

In spring of 2017, the JWC installed a new 24-inch insertion magnetic flow meter on the 24-inch finished water transmission main at the JWC Plant. The 24-inch insertion flow meter provided an opportunity to compare combined flows sent via 24-inch transmission main with the individual flows recorded at City of Hillsboro (COH) Dilley PRV and Forest Grove PRV facilities. Both facilities are located in Forest Grove, 1.5 miles NE from the treatment plant, close to the intersection of Hwy 47 and Elm Street.

Table 1 shows monthly flow volumes recorded at JWC 24-inch insertion flow meter and water volumes recorded at Dilley PRV and Forest Grove (FG) PRV facilities, compares differences, and calculates capture rates that indicated approximately 25% to 30% uncounted water loss.

Table 1 Monthly Water Volumes Recorded at Flow Meters

Month	Monthly Water Volumes (MG) Recorded at				Uncounted Water Volume (MG)	
	JWC 24" Insertion Flow Meter	Dilley PRV Magnetic Flow Meter	Forest Grove PRV Ultrasonic Flow Meter	Sum: Dilley PRV + FG PRV Water Volumes	JWC 24" Water Volume - (Dilley PRV + FG PRV) Water Volumes	Percent Capture
May-18	29.5	15.9	10.98	26.9	2.56	**91%**
Jun-18	45.4	12.2	27.33	39.5	5.92	**87%**
Jul-18	113.4	16.8	65.78	82.6	30.87	**73%**
Aug-18	132.9	14.0	80.87	94.9	38.01	**71%**
Sep-18	103.7	15.3	61.41	76.7	27.02	**74%**
Oct-18	82.0	14.2	47.38	61.6	20.35	**75%**

Uncounted water volumes may be caused by two main reasons:

1. Potential leaks from 24-inch transmission main, and/or,
2. Inaccuracy in flow/volume recorded at the JWC 24-inch insertion flow meter, COH Dilley PRV magnetic flow meter and/or FG PRV ultrasonic flow meter.

A flow testing procedure was developed, reviewed and approved by JWC, COH and Forest Grove representatives. Testing was conducted on March 27, 2019, to verify the accuracy of the water meters and potential leakage from 24-inch transmission main. A total of four tests were performed. The testing team consisted of Mike Anunsen and Alexis Cooley from COH Water Department, Jamie Davis and Adam Thompson from COH Water Operations, Jeff Wright from JWC WTP, and Brian Dixon, Richard Blackmun and Derek Robbins from the City of Forest Grove. All flow data recorded during testing was signed and approved by team members, and it is included in Attachment A of this memo.

2. Testing Procedure and Results

The testing included four tests. The test purpose and results are described in the following text. The site testing data is provided in Attachment A at the end of this memo. The Table 2 and Figures 1 to 4 were developed to numerically and graphically present original testing data and SCADA data recorded at the plant. Descriptions of each test and of the test results follows Table 2.

Table 2 Test Results

Dilley/Forest Grove/JWC 24" Meter Test Results

Wednesday, March 27, 2019

Procedure: Conference Call Phone Number 503-345-7637

Test #1 = Forest Grove and Dilley both Closed — Mike Anunsen will call the times.

Test #2 = Forest Grove closed, Dilley Open

Test #3 = Forest Grove Open, Dilley Closed

Test #4 = Forest Grove and Dilley Open

TEST #1	Target Flow	Time of Day	JWC Flow per Meter Display	Dilley Meter Display	Forest Grove Meter Display	Difference	Difference
Both Valves Closed	gpm	HR:MIN	gpm	gpm	gpm	gpm	%
	0	10:01:00 AM	0	0	0	0	0

TEST #2	Target Flow	Time of Day	JWC Flow per Meter Display	Dilley Meter Display	Forest Grove Meter Display	Difference	Difference
Dilley PRV Open	gpm	HR:MIN	gpm	gpm	gpm	gpm	%
FG PRV Closed	0	10:02:00 AM	0	0	Closed	0	
	250	10:07:00 AM	252	269	Closed	-17	7%
	500	10:11:00 AM	492	502	Closed	-10	2%
	750	10:14:00 AM	818	815	Closed	3	0%
	1000	10:18:00 AM	987	1000	Closed	-13	1%
	1500	10:22:00 AM	1514	1500	Closed	14	1%
	2000	NA	NA	NA	Closed		

TEST #3	Target Flow	Time of Day	JWC Flow per Meter Display	Dilley Meter Display	Forest Grove Meter Display	Difference	Difference
Dilley PRV Closed	gpm	HR:MIN	gpm	gpm	gpm	gpm	%
FG PRV Open	0	10:26:00 AM	0	Closed	0	0	
	250	10:31:00 AM	182	Closed	275	-93	41%
	500	10:40:00 AM	502	Closed	525	-23	4%
	750			Closed			
	1000	10:46:00 AM	1462	Closed	950	512	42%
	1500	10:50:00 AM	2225	Closed	1600	625	33%
	2000	10:54:00 AM	3085	Closed	2100	985	38%

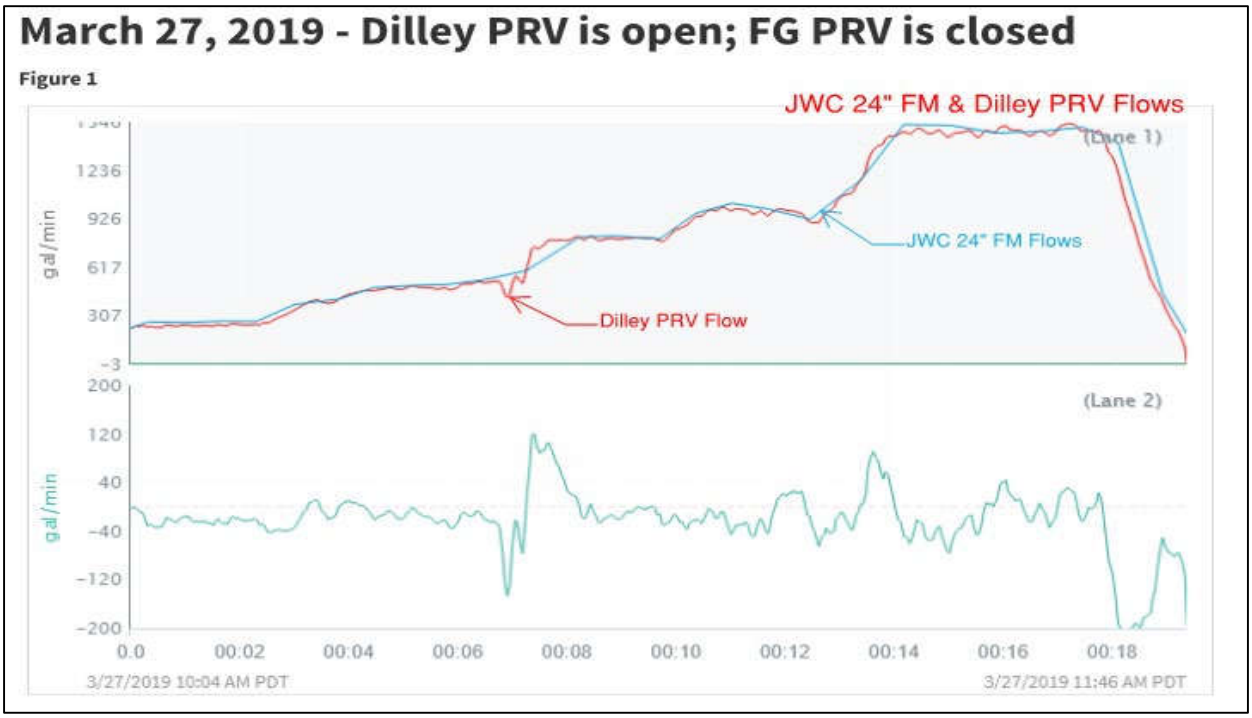
TEST #4	Target Flow	Time of Day	JWC Flow per Meter Display	Dilley Meter Display	Forest Grove Meter Display	FG+Dilley	Difference	Difference
Dilley PRV Open	gpm	HR:MIN	gpm	gpm	gpm	gpm	gpm	%
FG PRV Open	0	11:13:00 AM	0	0	0			
	250							
	500	11:24:00 AM	1012	550	400	950	62	6%
	750							
	1000	11:29:00 AM	2478	1020	975	1995	483	22%
	1500	11:33:00 AM	3915	1520	1500	3020	895	26%
	2000							

Test #1: Purpose - Check for leakage from JWC 24-inch Transmission Main
COH Dilley and FG PRVs fully closed (no flow) to check whether the 24-inch insertion flow meter at the plant records any flow.

Test #1: Results: No flows were recorded at the 24-inch insertion meter. This indicates that there is no leakage from 24-inch transmission line between the JWC Plant and Dilley and FG PRVs. For references see Attachment A, and Table 2-Test 1 data.

Test #2: Purpose - Compare flows at JWC 24-inch insertion flow meter and Dilley PRV magnetic flow meter to check for accuracy of both meters.
The Forest Grove PRV was closed during this test and Dilley PRV was open. The test was performed for different flow rates of 250, 500, 750, 1000, and 1500 gpm. Proposed test at 2000 gpm was cancelled by COH Operations due to a potential of overflowing Dilley reservoir. To achieve those flows valves in Dilley PRV station were throttled.

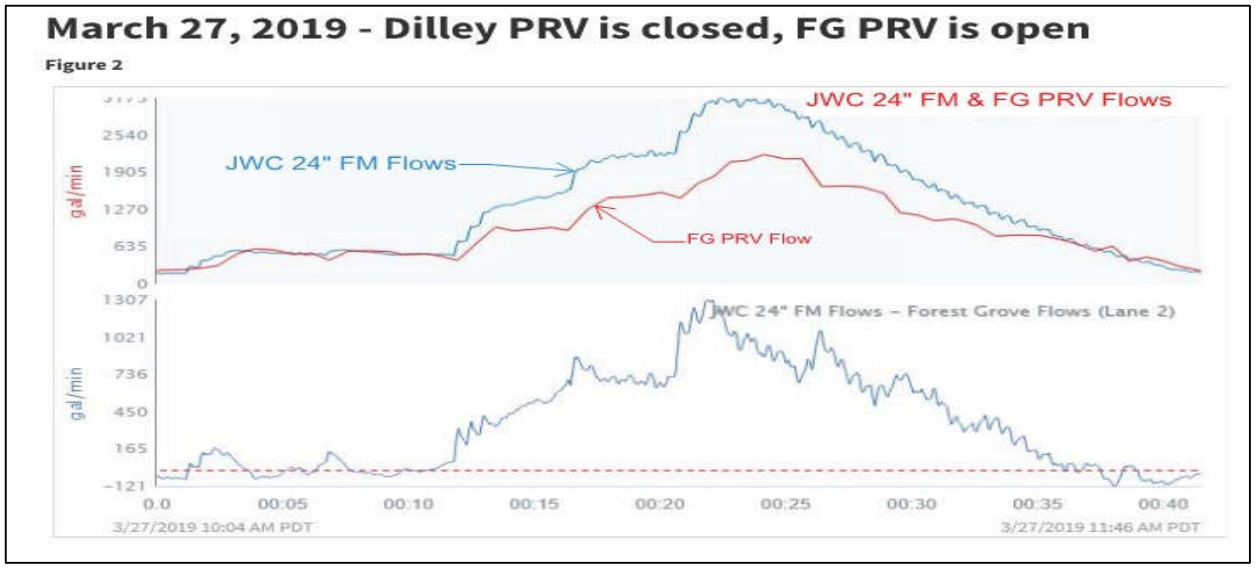
Test #2 Results: Flows recorded at different flow rates at COH Dilley PRV were almost identical with flows recorded at the JWC 24-inch insertion flow meter. This indicates that both the JWC 24-inch Insertion meter and the Dilley PRV magnetic meter operate at very high accuracy. See Attachment A, Table 2-Test 2, and Figure 1.



Test #3 Purpose: **Check for FG meter accuracy by comparing flows at JWC 24-inch insertion flow meter and FG PRV ultrasonic flow meter**

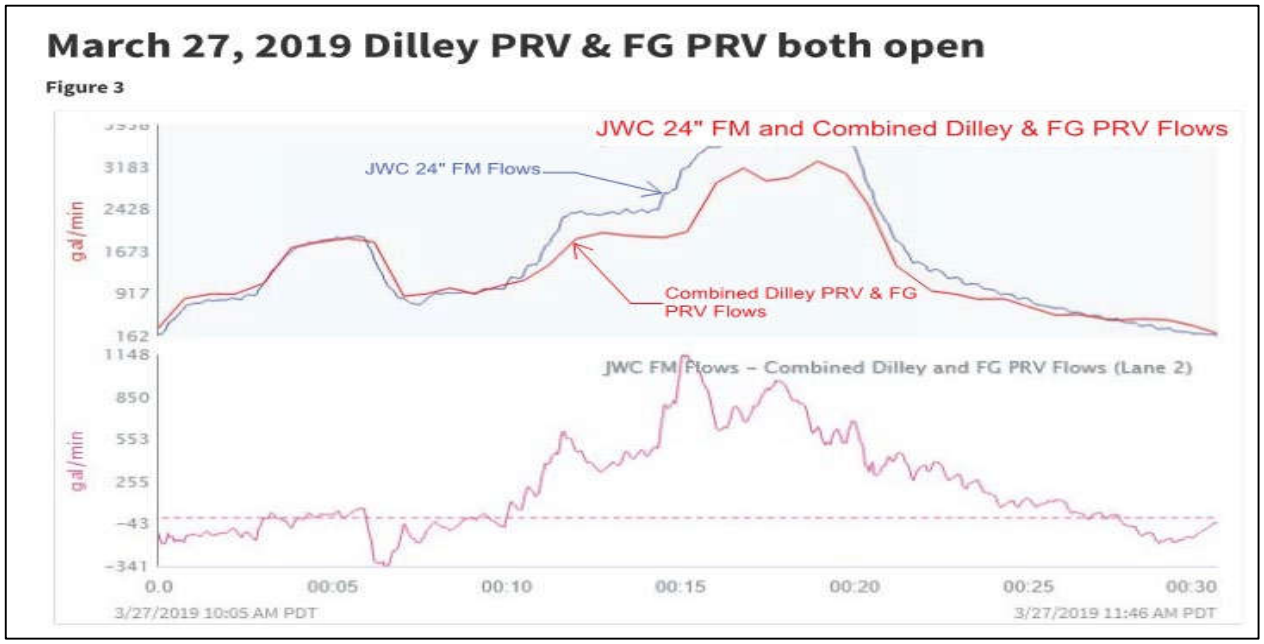
The Dilley PRV was closed during this test. The test was performed for different flow rates of 250, 500, 750, 1000, and 1500 gpm. To achieve those flows valves in FG PRV station were throttled. However, FG crew was not able to throttle their valves to establish constant flow of 750 gpm and the 750 gpm test was cancelled.

Test #3 Results: Flows recorded at Forest Grove PRV ultrasonic flow meter were significantly different from flows measured and recorded at the 24-inch insertion flow meter. The flows recorded at the FG ultrasonic flow meter were significantly lower than flows recorded at 24-inch Insertion meter. Since Test #2 indicated that the JWC 24-inch insertion meter provides accurate flow readings, this difference indicates potentially significant inaccuracy (under-reading) of the Forest Grove flow meter (see Attachment A, Table 2-Test 3, Figure 2).



<u>Test #4 - Purpose</u>: **Compare flows recorded at the JWC 24-inch insertion meter with combined flows recorded at Dilley PRV and Forest Grove PRV**.
Both the Dilley PRV and Forest Grove PRV were open, and valves at those locations were throttled to readings that showed delivery through each of the PRVs of half of the target flows through the JWC 24-inch insertion valve. The test was performed for different flow rates of 1000, 2500, and approximately 4000 gpm through JWC 24-inch insertion flow meter. The readings on the JWC 24-inch insertion meter should have equaled the sum of the flows recorded at the Dilley PRV and the FG PRV for each flow rate.

<u>Test #4 - Results:</u> Flow recorded at JWC 24-inch Insertion flow meter was significantly higher than combined flows at Dilley and FG PRVs, as shown in Attachment A, Table 2-Test #4 and Figure #3. Since Test #2 demonstrated the accuracy of JWC 24-inch meter and Dilley PRV, the Test #4 result indicates that the FG PRV is recording flows that are significantly lower than actual flow.



3. Further Evaluation

Two correlation graphs were developed based on March 27, 2019 flow testing data to establish relationship between Dilley PRV and the 24" Insertion Meter flows (Figure 4) and between Forest Grove PRV and the 24-inch Insertion Meter flows (Figure 5).

From Figure 4 it could be seen that flows of 250, 500, 750, 1000, and 1500 gpm measured and recorded at Dilley PRV flow meter were almost identical with related flows recorded at the same time at the 24-insertion flow meter. However, the Forest Grove flow meter (Figure 5) recorded significantly lower flows than the 24-inch Insertion flow meter. The orange line in Figure 5 shows the approximate line where the flow readings from the JWC 24-inch insertion meter should have been based on the readings on the FG PFV. (for example: 1500 gpm recorded at 24-inch insertion meter relates to approximately 1000 gpm recorded at FG PRV, and 3000 gpm recorded at 24" insertion flow meter relates to approximately 2000 gpm recorded at FG PRV). However, the actual flow readings in the JWC meter, as illustrated by the blue line, are significantly higher than the flow reading on the FG PRV.

Figure 4. Flows recorded at 24" insertion flow meter and Dilley PRV flow meter

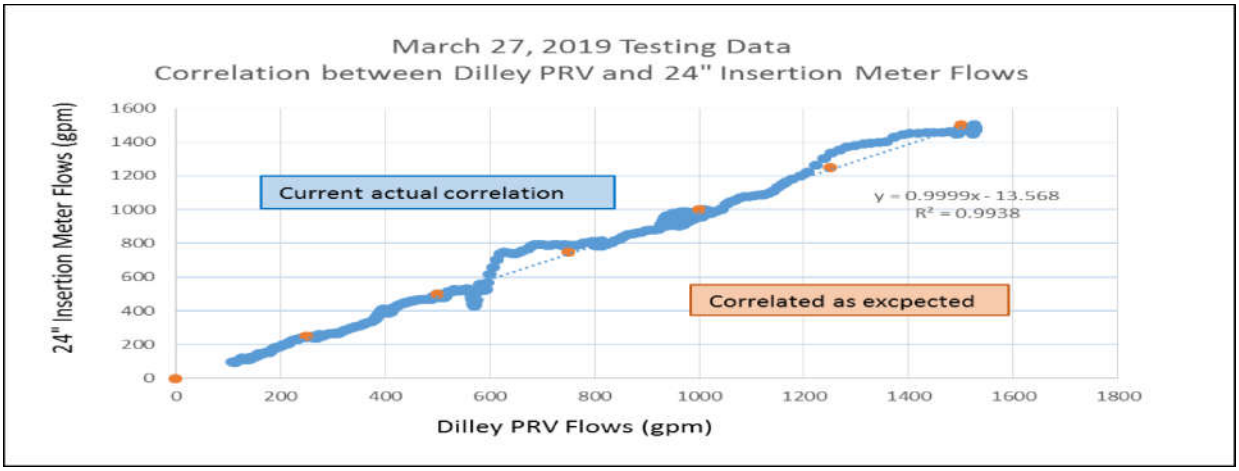
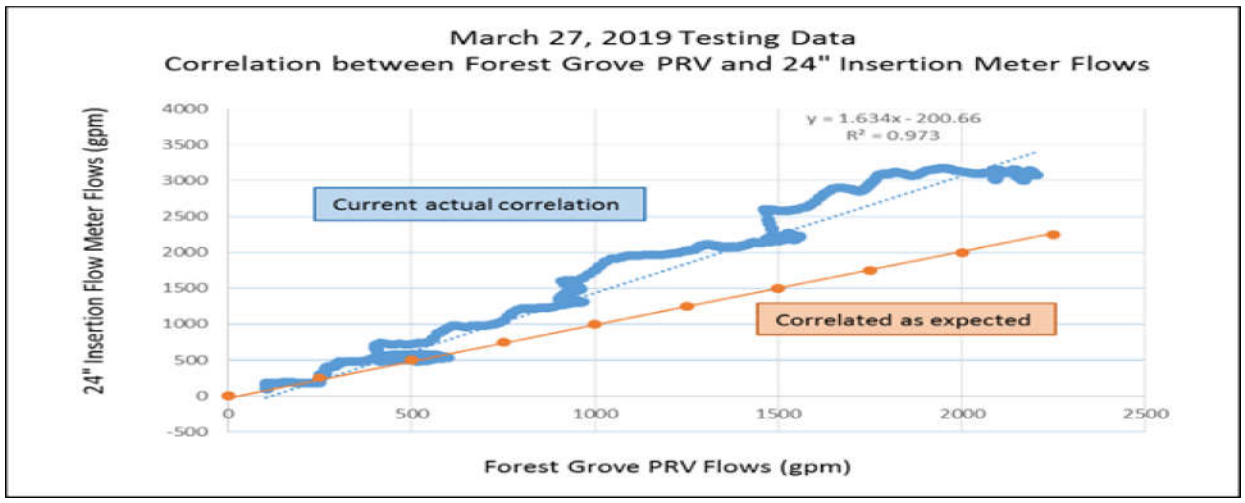


Figure 5. Flows recorded at 24" insertion flow meter and Forest Grove PRV flow meter



4. Recommendations

Based on testing results and further evaluation provided, JWC Staff recommend that the JWC General Manager meet with the Forest Grove management team to:

1. Develop a plan and schedule for Forest Grove meter replacement.
2. Discuss methodology to account for the meter inaccuracy by estimating future billings for water volumes used by Forest Grove, until the Forest Grove PRV flow meter is replaced.
    a. Staff proposes calculating the future estimated water volumes used by Forest Grove based on the difference in the monthly meter reads recorded at the JWC 24" insertion flow meter and at the Dilley meter.
3. Once a plan and schedule is developed for the Forest Grove meter replacement and for estimating water volumes used by Forest Grove, the plan will be presented to the JWC Operations Committee for their information.

Attachment A – Site Testing Data

JWC 24" Meter Worksheet

Wednesday, March 27, 2019

Procedure:

Test #1 = Forest Grove and Dilley both Closed
Test #2 = Forest Grove closed, Dilley Open
Test #3 = Forest Grove Open, Dilley Closed
Test #4 = Forest Grove and Dilley Open

Conference Call Phone Number 503 345-7637
Mike Andersen will call the times.

TEST #1	Target Flow	Time of Day	JWC Flow per Meter Display	Totalizer
Both Valves Closed	gmp	HR:MIN	gmp	gal
	0	10:01	0	1382946

TEST #2	Target Flow	Time of Day	JWC Flow per Meter Display	Totalizer
Dilley Open	gmp	HR:MIN	gmp	gal
Forest Grove Closed	0	1002	0	1382946
	250	1007	252	
	500	1011	492	
	750	1014	818	
	1000	1018	987	
	1500	1022	1514	
	2000			

TEST #3	Target Flow	Time of Day	JWC Flow per Meter Display	Totalizer
Dilley Closed	gmp	HR:MIN	gmp	gal
Forest Grove Open	0	1026	0	1382962
	250	1031	182	
	500	1040	502	
	750	- - -	-	
	1000	1046	1462	"+500"
	1500	1050	2225	"+700"
	2000	1054	7085	"+1000"

TEST #4	Target Flow	Time of Day	JWC Flow per Meter Display	Totalizer
Dilley Open	gmp	HR:MIN	gmp	gal
Forest Grove Open	0	1113		1383018
	250	- - -	-	
	500	1124	1012	
	750	- - -	-	
	1000	1129	2478	
	1500	1133	3915	
	2000	- - -		

Name: JEFF WRIGHT Signature: [signature] Date: 3-27-19

Dilley PRV/Meter Worksheet

Wednsday, March 27, 2019

Procedure:

Test #1 = Forest Grove and Dilley both Closed
Test #2 = Forest Grove closed, Dilley Open
Test #3 = Forest Grove Open, Dilley Closed
Test #4 = Forest Grove and Dilley Open

Conference Call Phone Number 503-345-7637
Mike Anunsen will call the times.

Replaced at

TEST #1 Both Valves Closed	Target Flow gmp	Time of Day HR:MIN	Dilley Flow per Meter Display gmp	Totalizer Kgal
	0	10:01 AM	0	1073189

Kgal 8"

TEST #2 Dilley Open Forest Grove Closed	Target Flow gmp	Time of Day HR:MIN	Dilley Flow per Meter Display gmp	Totalizer Kgal
	0	10:02 AM	0	1073189
	250	10:07 AM	269	
	500	10:11 AM	502	
	750	10:14 AM	815	
	1000	10:18 AM	1040	
	1500	10:22 AM	1500	
	2000			

Kgal

TEST #3 Dilley Closed Forest Grove Open	Target Flow gmp	Time of Day HR:MIN	Dilley Flow per Meter Display gmp	Totalizer ~~Kgal~~
	0	10:26	0	27.661
	250	10:31	275	
	500	10:40	525	
	750			
	1000	10:46	950	
	1500	10:50	1600	
	2000	10:54	2100	

MG.

PRV Flow Bounces ~ 100gpm +/- - Orings needs Replaced

TEST #4 Dilley Open Forest Grove Open	Target Flow gmp	Time of Day HR:MIN	Dilley Flow per Meter Display gmp		Totalizer K gal
	0	~~10~~ 11:13			1073206
	~~250~~				27.704
	500	11:24	550	400	
	~~750~~				
	1000	11:29	1020	975	
	1500	11:33	1520	1500	
	~~2000~~				

Dilley F.G.

Final 1073226 gal D.G. 27.724 mg FG

Name: Mike Anunsen Signature: Date: 3/27/19

Brian Dixon

APPENDIX C
EVALUATION OF GROUNDWATER SOURCE FOR EMERGENCY USE, GSI, 2020

MEMORANDUM - FINAL

Evaluation of Groundwater Source for Emergency Use for Forest Grove Water Master Plan

To: Rich Blackmun, PE (Forest Grove); Heidi Springer, PE (Murraysmith)

From: Ronan Igloria, PE; Rodrigo Prugue

Date: March 25, 2020

The City of Forest Grove (City) contracted with Murraysmith to prepare a Water Master Plan Update. As part of this effort, GSI Water Solutions, Inc. (GSI) as subconsultant to Murraysmith was tasked with evaluating groundwater wells as a water source for emergency use, in particular to support the City's seismic resiliency efforts. The City identified the need for this evaluation because emergency groundwater wells could be the only potable water supply available after the Cascadia Subduction Zone Earthquake (CSZE) until the City's water system backbone becomes seismically resilient.

This memorandum presents a summary of the evaluation. This memorandum was prepared in parallel to the Water System Master Plan Update (WSP) being prepared by Murraysmith and the Water System Seismic Resiliency Plan (SRP) being prepared by InferTerra. Details of the City's water system infrastructure and operations and resiliency goals are documented in those respective plans.

The scope of this effort to evaluate groundwater wells for emergency use is as follows:

1. Identify coordination opportunities with Washington County emergency response and operations;
2. Define preliminary level-of-service and operational concept for use of emergency wells;
3. Identify and assess the existing well network for potential emergency wells for further evaluation;
4. Develop recommendations for potential next steps.

This memorandum discuss the information related to each of the scope items above, and is intended as input to the City to decide whether to proceed with the contingency task assigned to GSI to conduct further evaluation of any specific well(s) identified in this evaluation.

1.0 Background and Related Planning Efforts

The City utilizes two sources of supply:

(1) City of Forest Grove Water Treatment Plant (FGWTP). The City has intake facilities within the Clear Creek watershed on Clear Creek, a tributary of Gales Creek, Roaring Creek, Thomas Creek, Deep Creek and Smith Creek.

(2) Joint Water Commission Water Treatment Plant (JWC WTP), which receives water from the Tualatin River watershed through the Springhill Intake and Pump Station. The City is a member of the JWC.

The City does not currently utilize groundwater as a source of supply and does not have any groundwater rights.

In 2018, the City started the development of the WMP. The WMP scope of work included a task to evaluate at a planning level, the potential for using groundwater as an emergency water supply. The City had not previously considered groundwater as an emergency source. Thus, no defined criteria or "level-of-service" had been developed for how groundwater wells or other sources could be used to provide emergency potable water supply after the CSZE or other events. The WMP provided an opportunity for the City to assess the feasibility of groundwater for emergency use, and included this work as part of the WMP update.

The primary purpose of this assessment is to determine if groundwater wells could be an option to provide water to the community for emergency use. It was beyond the scope of this effort to evaluate the types of hazards and risks or to define the range of emergencies for which groundwater wells could be used for supply. However, based on discussions with the City staff, the primary interest was to use groundwater wells in situations when residents lack access to water as a result of distribution system damage or when the City's water supplies are non-functioning for extended periods. Thus, for purposes of this assessment it was assumed that the "emergency" scenario is a major seismic event like the Cascadia Subduction Zone (CSZ), because of its anticipated catastrophic impacts.

The SRP also focuses on the CSZ for its analysis and planning. The SRP mapped the geohazards around the City (e.g. susceptibility to liquefaction, spread, settlement, and landslides), and identified the water system "backbone" infrastructure (raw and finished water transmission lines, major water distribution lines). The geohazard maps inform geologic risk areas for groundwater wells. Preliminary SRP information was used in this assessment as follows:

- Areas with higher geohazard risks pose greater risk for damaged or non-functioning groundwater wells after a seismic event. For example liquefaction may cause groundwater supplies to change and or damage the well casing and related pumping equipment. In general, wells located in lower geohazrd risk areas are preferred for emergency use.
- The backbone infrastructure maps inform the location of groundwater wells relative to these backbone components when considering how the well supplies may complement distribution of water after a seismic event. For system security purposes the backbone infrastructure is not presented in this memo, but the information was used in this assessment to determine the location of potential emergency wells to the backbone of the water distribution system.

The *Washington County Emergency Operations Plan Functional Annex – Catastrophic Mass Reception* document (https://www.co.washington.or.us/EmergencyManagement/upload/FA-C_CatastrophicMassReception_Approved9_24_2010.pdf) lists the following sites as emergency centers for the City:

- Pacific University Athletic Center
- Tom McCall Upper Elementary School
- Neil Armstrong Middle School

- Forest Grove High School

The mission of each Reception Center is to provide a safe environment for evacuees seeking critical respite services. They are intended to be a centralized location with basic resources. With this in mind, the assessment reviewed the proximity of existing wells relative to the four reception centers in the City.

2.0 Level-of-Service and Operational Concepts

The Oregon Health Authority Public Health Division requires that all public water systems maintain a current emergency operations plan and incorporate the results of security vulnerability assessments into the plan. One required component of the emergency operations plan as stated by the Oregon Administrative Rules (OAR), is a plan for emergency water: public water systems shall develop a plan for emergency water to include the rationing of drinking water, identifying and utilizing alternative drinking water sources and supplies, and alternative distribution of drinking water. (OAR 333-061-0064 (1)(e)(D)(ii)).

The City has not defined explicit levels-of-service for these emergency wells relative to other emergency supply options that may be considered as part of its resiliency planning and water master planning efforts. For purposes of this study, the concept assumes that the City will use wells for emergency water supply purposes only. The document "Planning for an Emergency Drinking Water Supply" (EPA, 2011), noted that a value of 1 gallon per person per day is a reasonable planning number, consistent with the Federal Emergency Management Agency (FEMA), U.S. Environmental Protection Agency (EPA), and the American Red Cross estimates for drinking, food preparation, and hygiene related to health and safety. Emergency water required for firefighting, hygiene, and other needs (e.g., domestic animals) would be considered beyond the objective of the emergency drinking water supply.

Based on this preliminary level of service, a well production capacity of 20 gallons per minute (gpm) would produce approximately 28,800 gallons per day (gpd). With a current City population of approximately 25,000, and projected population of approximately 45,000 in 2069, the City can plan to develop two to four groundwater wells with 10 to 30 gpm production rates. These wells can be developed over the next 10 years depending on the actual well production rates and would be sufficient to meet minimum domestic water supply needs for the City.

Following guidance from the Oregon Resiliency Plan, the City's SRP identified the goal to have drinking water available at 50 percent operational levels within 1 to 3 days and at 80 percent operational levels within 3 to 7 days at community distribution points. During this period, the City would be working to restore supply capacity at its main supply source, as well as repairing distribution system damage. It should be noted that the ORP identifies these as target goals with the expectation that it will take years or decades in some cases to be able to meet, because of the financial burdens on utilities and customers. The City of Forest Grove does not currently meet these goals, and anticipates needing 30 to 50 years (or more) to meet these ORP goals. This is one reason that the City is looking at groundwater wells as potential option to help meet emergency water supply needs in a more near-term timeline.

In the event of a system-wide emergency, water delivered to the City's customers must meet drinking water criteria to be considered potable water. If water does not meet the potable water criteria, then it could be delivered as non-potable water to customers. This includes any well water or unapproved sources of water. In an emergency, the City could consider delivering chlorinated groundwater of

unknown water quality. The water could be sampled at the delivery tap for each well site, and must be absent of total coliform and E. coli bacteria (e.g. testing for presence/absence with field testing method). This water would be considered non-potable but bacteria free. The water would also be sampled for nitrate and arsenic prior to use to verify that it is below the OHA MCLs. Coliform bacteria, nitrate, and arsenic are the acute contaminants of concern in an emergency.

3.0 Evaluation of Existing Well Network

3.1 Hydrogeologic Setting

The summary of hydrogeologic setting presented below is based on work that GSI completed for the City documented in the tech memo "Aquifer Storage and Recovery Feasibility Study for the City of Forest Grove" dated May 17, 2005. The 2005 study concluded that the City not invest in exploring aquifer storage and recovery (ASR) because the primary target aquifer in the area is limited in extent and have low yield potentials. However, feasibility of ASR is different than the using groundwater for emergency well production at the production rates discussed above.

The predominant geologic units of the area, from youngest to oldest, include, relatively fine-grained unconsolidated sediments, Columbia River Basalt Group (CRBG), older marine sediments, and older volcanic rocks.

Unconsolidated Sediments. These units consist of recent undifferentiated sediments predominantly in the drainages (Qal) and also consist of fluvial and lacustrine deposits. The latter consists of unconsolidated to semi-consolidated sediments that are predominantly fine-grained silts and clays with thin discontinuous lenses of sand and gravel. The thickness of the unconsolidated sediments overlying older rocks, including CRBG, ranges from less than 25 feet near the margins of the hills to more than 200 feet farther east of town. These sediments typically have limited extent and variable permeability, and are discontinuous in nature. This unit is not a very highly reliable and productive aquifer; however, some wells completed in this unit could meet emergency water supply needs.

Columbia River Basalt Group (CRBG). The CRBG consists of a series of basalt lava flows originating from eastern Washington, Oregon, and western Idaho that underlie a large area in the Willamette and Tualatin valleys. The CRBG in the Forest Grove area is represented by two distinct groups of flows comprising the Wanapum (Tcw) and the Grande Ronde (Tcg) formations. Groundwater in the basalt is predominantly derived from interflow zones, which represent the contact between individual basalt flows. These interflow zones are typically rubbly and porous, and thus can transmit water easily. Groundwater is also produced from fractured zones in the more massive interior flows of the CRBG if sufficient structural deformation and fracturing has occurred. The basalt contains some of the most water productive aquifers in the area.

Older Sedimentary Rock. These materials consist of marine sediments that typically do not host productive aquifers in the Tualatin basin. However, numerous domestic wells along David Hill tap these sediments (consisting of clays, claystone, sand, and sandstones) for domestic use (i.e. low production rates). In deeper portions of the Tualatin Basin and in faulted areas along the margin, the marine sediments often contain saline water. The water quality in some basalt wells in the region has been affected by saline water migrating up into the basalt from underlying marine sediments.

Older Volcanic Rocks. These materials consist of basaltic flows and breccias and sub-marine basalt breccias, pillow lavas with interbedded basaltic sandstones, siltstones and conglomerates. Little hydrogeologic data are available for these units.

3.2 Evaluation of Existing Wells

An inventory of water wells for the area around Forest Grove was prepared to obtain information about local wells and subsurface conditions. A total of 37 wells (not abandoned) were identified within approximately 2 mile radius of the City center, using data available from Oregon Water Resources Department (OWRD) well database. There can be a discrepancy between what is in the OWRD database and actual field conditions. In some cases, wells may have been improperly abandoned or not reported to the state. The scope and purpose of this assessment is to conduct a high-level and preliminary analysis. The City may decide to conduct additional field confirmation for select sites. Any other sites not identified in the OWRD database would need to be identified through direct contact with or from landowners. The extent of the search area and the wells identified in the search are shown in Figure 1. The inventory included five wells completed in basalt (CRBG) and the remaining 32 wells completed in unconsolidated sediments. Attachment A includes a list of all the wells identified in the search. The well data includes, location, owner, construction date, depth, water level, and well discharge rate (capacity). Based on OWRD well records available at the time of this assessment, a majority of the wells identified are private wells located throughout the service area[1]. Most of the wells are located on the northern part of the service area or just north of the service area boundary. Three wells are located in the southeast part of the service area.

Reported yields for wells completed in the basalt range from less than 15 gpm to 72 gpm and yields for wells completed in sediments range from less than 1 gpm to more than 320 gpm. Most of the wells completed in sediments yield less than 50 gpm. Specific capacity is an additional parameter used to better understand the relative performance and productivity of wells. This value is a ratio of a well's yield per foot of drawdown and can be used to assess the relative performance of a well and the productivity of the aquifer. Most of the wells identified in or near the City did not have sufficient hydraulic data to calculate a specific capacity. However, for those with sufficient data, specific capacities in the sediment wells ranged from 0.03 gallons per minute per foot of drawdown (gpm/ft) to 10 gpm/ft, while specific capacities for basalt wells ranged from less than 0.07 gpm/ft to 0.27gpm/ft. The two wells with the highest specific capacities are in the sediment units. Well WASH 6429 had yield of 50 gpm with a specific capacity of 10 gpm/ft, and WASH 10597 had a yield of 320 gpm with a specific capacity of 2.5 gpm/ft. It should be noted that these specific capacity values are time-dependent, and because most of these data are based on short interval test data there is uncertainty in the values.

Static groundwater levels from well driller's logs were reviewed to evaluate depth to water in wells completed in sediments and basalt. Static water levels in sediment wells ranged from 0 to 265 feet below ground surface (bgs), while water levels in basalt wells ranged from 0 to 64 feet bgs. Wells completed in basalt along the northeast side of David Hill often are flowing (artesian), which may be the result of structures (faults) along the base of the foothills. In addition, the CRBG aquifer in this area is confined and aquifer is under pressure, which means wells that penetrate this unit have a shallower static water level caused by the pressure in the CRBG.

The evaluation of the wells were based on several criteria including available and complete logs, available pump test data, and location relative to high geohazard risk areas. As mentioned earlier, pump test or production test data was limited for the 37 wells that were considered for this evaluation. In addition, the wells evaluated predominantly were located in areas susceptible to liquefaction in the event of an earthquake or similar geologic event. After considering the quality of

[1] OWRD records may not be up-to-date. Ownership of the wells and their water rights would transfer to the purchasing owner of the property when sold.

well data, location relative to geohazards, and proximity to Catastrophe Reception Centers and backbone infrastructure, GSI recommends further evaluation of the following two wells:

1. WASH 10597[2]
2. WASH 60859

WASH 10597 is completed in an alluvial aquifer and has a high listed well yield of 320 gpm. It is located in the southeast part of the City service areas near the Neil Armstrong Middle School Reception Center. WASH 60859 has a listed capacity of 72 gpm and is completed in competent basalt. It is located in the north-northwest area just north of the City service area and closest to the Forest Grove High School Reception Center.

It should be noted, and as stated in the introduction of this memorandum, that the well screening process in this section was completed without any City defined emergency water supply strategy or level of service. The prioritization or selection of wells for further assessment could change based on the strategy when established by the City.

4.0 Implementation Considerations

As noted above, the concept is that the City would use these wells only if needed after a catastrophic event causing major damage to its primary water supply, transmission, and distribution. Otherwise, the wells would be operated annually to ensure they are functioning. These wells would likely have to be outfitted with auxiliary power supplies and disinfection equipment, evaluated to determine seismic resistance and agreements would be needed with owners.

For existing wells, the City would not need to apply for a new water right. If the City decides to construct a new well, a well construction permit would need to be secured, and the City could discuss options with Oregon Water Resources Department (OWRD) about the water right permitting requirements. OWRD may require a water right permit or limited license for the new well depending on how the City plans to use the well as an emergency source. Costs for a new well depend on the specific location, aquifer type (e.g. alluvium or basalt), design (e.g. well diameter and screen material), and depth of the well. For planning purposes and for wells approximately the same size (diameter and depth) as WASH 10597 and WASH 60859 identified in the previous section, the costs would be on the order of $150,000 to $300,000. Shallow (~100 feet), alluvial wells would be on the lower cost range, and deeper (>250 feet), basalt wells would be on the higher cost range.

Treatment is not required for groundwater sources as long as the wells are not under the influence of surface water, and the City can demonstrate that the groundwater meets drinking water requirements for coliform bacteria, nitrate, and arsenic. These are the acute contaminants of concern in an emergency. OHA recommends collecting water quality samples of the well ideally on an annual basis

5.0 Next Steps

This memo summarized the assessment to identify groundwater well(s) that may potentially serve as emergency source of water after a catastrophic event where the City's main water supplies may not function for extended periods. The scope of work was to recommend up to three wells to evaluate

[2] Note, this well is the same as one of the wells that City staff identified as a well of interest (WASH 70665). WASH 10597 is the original well log, and WASH 70665 was simply an alteration.

further. Based on the evaluation presented above, GSI identified two wells that the City could review further.

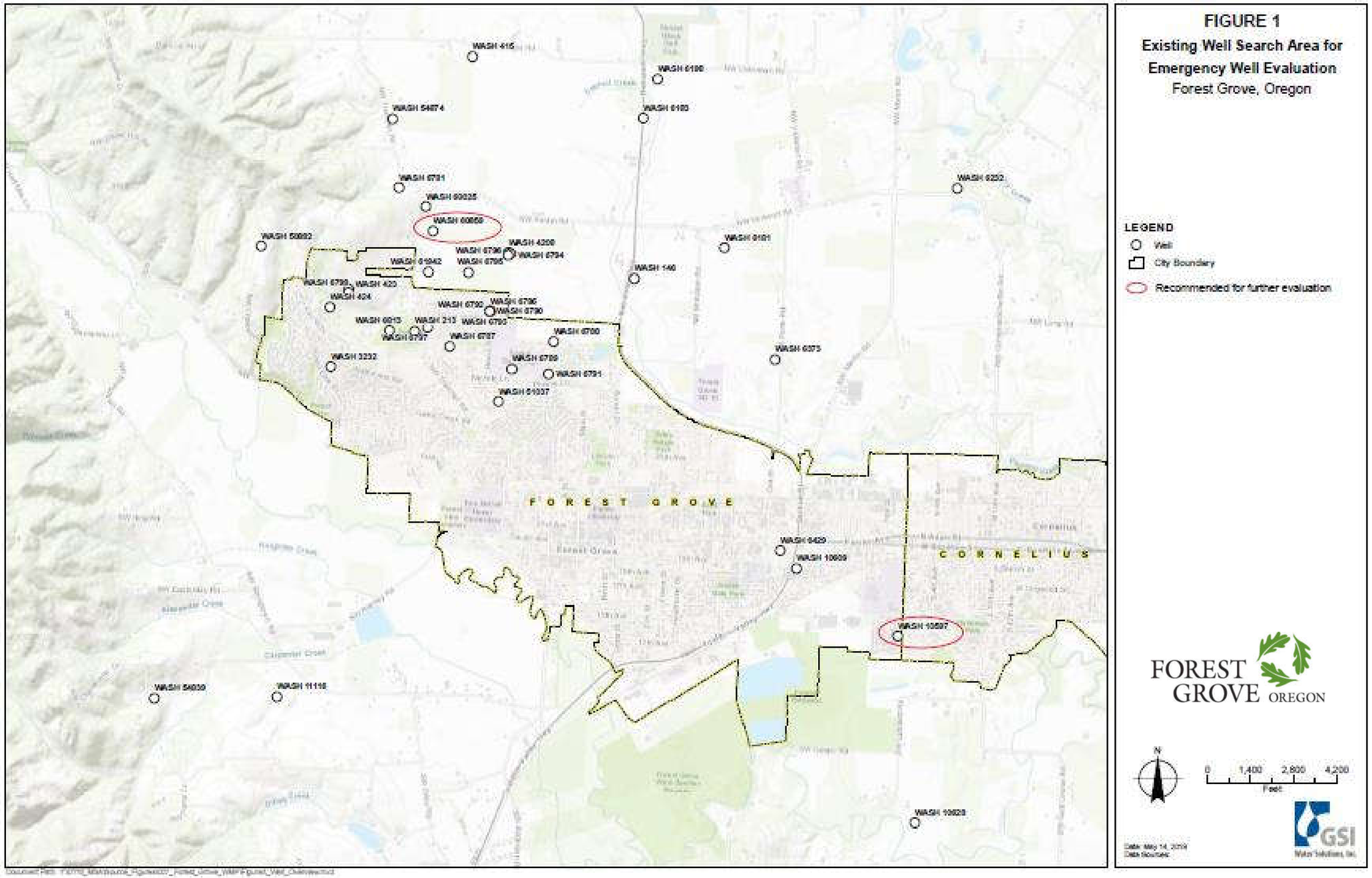
If the City decides to conduct the next evaluation step, the scoped contingency tasks included:

- Review of any existing water rights for the well;
- Map setback requirements for drinking water wells and potential contaminant risks based on review DEQ database information;
- Conduct site visit to ground-truth accessibility and potential issues for use of the well as an emergency source;
- Outline steps to secure use of the well (i.e. water rights administration, property owner access agreement); description of associated equipment needs; and
- Evaluate drilling a new well at the target sites against using the existing well (or rehabilitating the existing well if needed). Evaluation will include planning level costs for a new well at the target sites

If the City decides to look further into using groundwater wells for emergency use, the City should also consider the following as part of finalizing the WMP:

- Define specific levels of service for potential emergency wells to develop facility layout and equipment needs and sizing. For example, even if a well can produce more than 200 gpm, the City may decide to develop these emergency supply sites to distribute on the order of 50 gpm to simplify operation and maintenance issues.
- Contact well owner to determine if they are willing to consider having the City evaluate their well as a potential emergency backup supply for the community. Pursue access agreement to the well to test the well's performance, collect and analyze a water quality samples to evaluate the need for treatment to make the water is potable; evaluate the well and pump condition, which includes pump testing the well for an extended period of time (multiple days), and pulling the pump system and completing a video log of the well, followed by reinstalling the existing pump system.

It should be noted the two wells were identified without the City having defined their emergency water supply strategy and associated level of service. Ideally, the City will develop their strategy for emergency potable water supply and associated levels of service prior to further evaluation of groundwater wells and other potential sources for emergency water supply.


WASH 416
WASH 6100
WASH 54874
WASH 6103
WASH 6791
WASH 60025
WASH 60858
WASH 6252
WASH 59892
WASH 4200
WASH 6796
WASH 6794
WASH 6795
WASH 6101
WASH 61042
WASH 146
WASH 6793
WASH 422
WASH 424
WASH 6792
WASH 6796
WASH 6790
WASH 6013
WASH 213
WASH 6792
WASH 6797
WASH 6787
WASH 6788
WASH 3232
WASH 6789
WASH 6375
WASH 6791
WASH 61037
FOREST GROVE
WASH 6420
WASH 10609
CORNELIUS
WASH 10597
WASH 54030
WASH 11116
WASH 10623
FIGURE 1
Existing Well Search Area for Emergency Well Evaluation
Forest Grove, Oregon
LEGEND
Well
City Boundary
Recommended for further evaluation
FOREST GROVE OREGON
N
0
1,400
2,800
4,200
Feet
GSI
Water Solutions, Inc.

Attachment A – Existing Wells Evaluated

Attachment A-1. Water Production Data for Wells Evaluated in Study

OWRD Primary Well ID Number		Altitude (ft. mean sea level)	Hole Depth (feet below ground surface)	Water Level (feet below ground surface)	Date of Water Level	Discharge (gallons per minute)	Drawdown (feet below ground surface)	Specific Capacity (Discharge/ Drawdown)
WASH	146	175.00	960.00	13	00035384	35	N/A	
WASH	213	240.00	223.00	64	7/21/1990	60	223	0.27
WASH	415	N/A	525.00	Artesian	3/11/1973	40	N/A	
WASH	423	N/A	215.00	75	10/7/1989	18	N/A	
WASH	424	N/A	295.00	50	9/23/1977	35	N/A	
WASH	3232	N/A	300.00	50	7/15/1993	15	N/A	
WASH	4208*	N/A	N/A	N/A	N/A	N/A	N/A	
WASH	6181	185.00	80.00	20	3/10/1998	8	N/A	
WASH	6183	181.00	535.00	265	6/4/1986	1	2	0.50
WASH	6198	185.00	260.00	76	00033476	100	200	0.50
WASH	6232	165.00	220.00	15	00001947	20	N/A	
WASH	6373	200.00	125.00	20	08241950	15	N/A	
WASH	6429	175.00	177.00	25	8/1929	50	5	10.00
WASH	6781	275.00	301.00	Artesian	7/1950	36	166	0.22
WASH	6786	N/A	270.00	30	7/11/1987	50	N/A	
WASH	6787	N/A	400.00	10	6/11/1987	40	N/A	
WASH	6788	N/A	105.00	21	9/13/1979	10	N/A	
WASH	6789	N/A	302.00	28	10/31/1975	10	N/A	
WASH	6790	N/A	205.00	29	3/14/1966	5	N/A	
WASH	6791	N/A	361.00	8	6/20/1975	8	N/A	
WASH	6792	N/A	304.00	4	5/29/1963	20	N/A	
WASH	6793	N/A	267.00	25	7/5/1963	4	N/A	
WASH	6794	N/A	69.00	25	9/30/1950	N/A	N/A	
WASH	6795	200.00	158.00	N/A	N/A	N/A	N/A	
WASH	6796	N/A	120.00	15	11/7/1988	20	N/A	
WASH	6797	N/A	490.00	6	4/30/1956	8	N/A	
WASH	6798	N/A	200.00	Artesian	10/5/1987	5	195	0.03
WASH	6813	N/A	57.00	N/A	N/A	N/A	N/A	
WASH	10597	167.00	260.00	12	6/4/1969	320	128	2.50
WASH	10609	173.00	130.00	30	00018594	30	35	0.86
WASH	10628	160.00	80.00	18	00034151	40	N/A	
WASH	11116	175.00	92.00	8	00018640	N/A	N/A	
WASH	50882	N/A	35.00	N/A	6/4/1996	N/A	N/A	
WASH	51037	N/A	91.00	4	6/28/1996	N/A	N/A	
WASH	54839	N/A	343.00	Artesian	6/24/1999	25	N/A	
WASH	54874	N/A	305.00	31	7/9/1999	15	219	0.07
WASH	60025	N/A	405.00	52	8/19/2003	9	298	0.03
WASH	60859	240.00	286.00	Artesian	11/6/2004	72	N/A	
WASH	61942*	N/A	260.00	70	12/30/2004	N/A	N/A	

** - Well has been abandoned.*

Attachment A-2. Owner and Location Information for Wells Evaluated in Study

OWRD Primary Well ID Number		USGS Site ID	Location by Township-Range-Section	Owner Name (in OWRD database)	Recorded Drill Date	Deepened (Y); Abandoned (A)	Well Known to be in Basalt Aquifer? (Y)	Depth to Competent Basalt (feet below ground surface)
WASH	146	453242123062201	01N/03W-30BDB1	VAN DYKE SEED CO., INC	9/18/1990	N/A		
WASH	213		01N/04W-26SENE	GARY, BILL	7/21/1990	N/A	Y	196
WASH	415			DAVIS, FLORIAN	3/11/1973	N/A	Y	425
WASH	423		01N/04W-26SENE	MARRE, WILLIAM	10/7/1989	N/A		
WASH	424		01N/04W-26	HABERMAN, RICHARD A	9/23/1977	N/A		
WASH	3232		01N/04W-26	MATIACO, STEVE	7/15/1993	N/A		
WASH	4208*		01N/04W-25NWNE	MARSHALL, TOM	10/10/1994	A		
WASH	6181	453253123054101	01N/03W-30AAA1	HAMMOND, RICHARD	3/10/1998	N/A		
WASH	6183	453334123062001	01N/03W-19BDA	MEEUWSEN, HAROLD	6/4/1986	N/A		
WASH	6198	453347123061401	01N/03W-19BAA	Sunset Grove Golf Club	10/29/1968	N/A		
WASH	6232	453314123035601	01N/03W-21CAC	MARSH, BILL	1947	N/A		
WASH	6373	453218123051601	01N/03W-29CBD	MATHISON, M.C.	8/24/1950	N/A		
WASH	6429	453117123051101	01N/03W-32CDC	MASONIC AND EASTERN STAR HOME	8/1929	Y		
WASH	6781	453309123081001	01N/04W-23DDA	GOFF, ARNOLD	7/1950	N/A	Y	168
WASH	6786		01N/04W-25	HOODENPILE, RAY	7/11/1987	N/A		
WASH	6787		01N/04W-25SW	VANAKER, BUD	6/11/1987	N/A		
WASH	6788		01N/04W-25NESE	VANDERZANDEN, KERRY	9/13/1979	N/A		
WASH	6789		01N/04W-25NESW	KNODEL, LARRY	10/31/1975	N/A		
WASH	6790		01N/04W-25	HOODENPYL, RAYMOND L	3/14/1966	N/A		
WASH	6791		01N/04W-25SESE	VAN DYKE, FRANK	6/20/1975	N/A		
WASH	6792		01N/04W-25	FRANKE, HERBERT P	5/29/1963	N/A		
WASH	6793		01N/04W-25	JOHNSON, WAYNE	7/5/1963	N/A		
WASH	6794		01N/04W-25NWNE	PURDIN, IRA LEE	9/30/1950	N/A		
WASH	6795		01N/04W-25SENW	RUETER, E A	N/A	N/A		
WASH	6796		01N/04W-25NWNE	SPIESSCHAERT, MAE	11/7/1988	N/A		
WASH	6797		01N/04W-25NWSW	DR R	4/30/1956	Y		
WASH	6798		01N/04W-26SENE	MARTENS, ROBERT	10/5/1987	N/A		
WASH	6813		01N/04W-26NESE	RUSSELL, FRANK	N/A	N/A		
WASH	10597	453051123041501	01S/03W-04BCC	FOREST GROVE SCHOOL DIST NO 1	6/4/1969	N/A		
WASH	10609	453111123050301	01S/03W-05BAA	STEVENS, W.E.	1950	N/A		
WASH	10628	452951123042601	01S/03W-08DAA	LEFORE, LOYAL	9/18/1987	N/A		
WASH	11116	453025123085701	01S/04W-02CCD	RITCHEY, CURTIS R.	1950	N/A		
WASH	50882		01N/04W-26SWNW	TURNBULL, DAVE	6/4/1996	N/A		
WASH	51037		01N/04W-25SWSE		6/28/1996	N/A		
WASH	54839			KURTZ, KERRY	6/24/1999	N/A	Y	10
WASH	54874			DOBER, BOB	7/9/1999	N/A	Y	236
WASH	60025			STUCK, FLOYD	8/19/2003	N/A		
WASH	60859		01N/04W-25NWNW	HUNTER, DAVID	11/6/2004	N/A	Y	248
WASH	61942*		01N/04W-25NWSW	DAVID HILL DEVELOPMENT; DOW BROTHERS	12/30/2004	A		

** - Well has been abandoned.*

APPENDIX D
JOINT WATER COMMISSION BARNEY AGREEMENT

JOINT WATER COMMISSION
WATER SERVICE AGREEMENT

EXHIBIT A

BARNEY AGREEMENT

JOINT OWNERSHIP AGREEMENT
BARNEY PROJECT

DATED OCTOBER 27, 2003

BY AND AMONG

CITY OF HILLSBORO,

CITY OF FOREST GROVE,

CITY OF BEAVERTON,

TUALATIN VALLEY WATER DISTRICT AND

CLEAN WATER SERVICES OF WASHINGTON COUNTY

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SECTION 4

VALUE OF RESERVOIR, OWNERSHIP, PURCHASE RIGHTS, LEASING PROVISION AND OPERATION COSTS

4.1 Value of Project

The value of the Project is provided in Exhibit A to this Agreement, which Exhibit may be updated and revised by resolution of the Commission from time to time.

4.2 Ownership Rights

The ownership of the Project is as follows:

Hillsboro	6,200 Ac. Ft. [1]	31.0%
Forest Grove	500 Ac. Ft. [1]	2.5%
Beaverton	4,300 Ac. Ft. [1]	21.5%
TVWD	7,000 Ac. Ft. [1]	35.0%
CWS	2,000 Ac. Ft. [1]	10.0%
Total	20,000 Ac. Ft. [1]	100.0%

[1] Actual amount of water available is dependent on the pond level, fish flow requirements, dead storage and inflow.

The Parties understand that the amount of Stored Raw Water available to the Party is determined as a percentage (based on ownership) of the total Stored Raw Water available to the Parties.

4.3 Buy-Back Rights

It is understood and agreed that certain flexibility is desired as to the ability to use the Stored Raw Water for beneficial municipal and

industrial purposes. To that end the Parties further agree that Beaverton and Forest Grove shall have the right to obtain 1,700 acre feet and 800 acre feet, respectively, from the share allocated to TVWD. Upon notice of election to seek these waters, or any part thereof, the Party seeking them shall give TVWD and the remaining members of the Commission written notice. The notice provisions and price paid by the Party seeking purchase from TVWD shall be as set forth in Exhibit C, which exhibit may be updated and revised by resolution of the Commission. Any change in Exhibit C by resolution of the Commission shall require a unanimous vote of the Commission.

4.4 Leasing Provisions

The JWC members have entered into an agreement entitled Joint Water Commission Hillsboro, Forest Grove, Beaverton and Tualatin Valley Water District Water Service Agreement dated _____ 2003, which provides for leasing of Stored Raw Water among the JWC members. This includes leasing of Stored Raw Water from the Project. The Parties to this Agreement agree to allow the JWC members to lease capacity among themselves.

The Parties further agree, to the extent that, after JWC members execute these lease rights, there is excess surplus water available from the Project for that year, that CWS shall have the right to utilize and purchase such water for increased flow augmentation. The terms and conditions of the purchase by CWS shall be as set forth in Exhibit D, which exhibit may be

updated and revised by resolution of the Commission. Any change in Exhibit D by resolution of the Commission shall require a unanimous vote of the Commission.

4.5 Payment of Operational Costs

Invoices for operational costs shall be submitted by the Managing Agency no less frequently than quarterly and shall be payable within thirty (30) days following receipt of invoice. Any funds not paid within such thirty (30) day period shall be deemed delinquent and shall draw interest at the rate of 9% per annum. If not paid within 180 days from date of invoice the matter shall be referred to the full Commission which may elect to resolve the matter in any equitable way and, in the event no such way can be agreed upon, in accordance with Section 7 of this Agreement.

4.6 Renewal and Replacements and System Upgrades

The Commission shall budget for renewals and replacements and upgrades, equipment replacement reserves and contingencies in accordance with Section 3.7 of this Agreement. The Parties shall make payments as required for renewals and replacements and upgrades and equipment replacement reserves proportional to the Party's ownership in the Project in relationship to the total ownership in the Project. The Parties shall make payments as required for contingencies based on the purpose for the contingency.

BARNEY JOINT OWNERSHIP AGREEMENT

EXHIBIT C

BUY-BACK RIGHTS
TERMS AND CONDITIONS

The amount of the buy-back right water requested shall be transferred to the requesting party with Buy Back-Rights not later than four (4) years following the date of the written notice of election. The parties with Buy-Back Rights further agree that every good faith attempt shall be made among the parties to expedite the repurchase and to alleviate any hardship which the repurchase may impose on TVWD. The amount and time of the payment for the repurchase shall be agreed between the requesting party with Buy-Back Rights and the TVWD.

BARNEY JOINT OWNERSHIP AGREEMENT

EXHIBIT D

SURPLUS WATER SALES RATE

APPENDIX E
TASK 3 CONDITION ASSESSMENT, MURRAYSMITH, 2019

Memorandum

Date:	February 13, 2019
Project:	Forest Grove Water System Master Plan (18-2197)
To:	Mr. Rich Blackmun, P.E. City of Forest Grove Engineering
From:	Heidi Springer, P.E. Murraysmith
Re:	Water Facility Condition Documentation

Introduction

The purpose of this memo is to document City of Forest Grove (City) Public Works and Engineering staff observations on the age and condition of City water facilities. This memo will be used to inform development of a proposed capital improvement program (CIP) for the City's Water System Master Plan (WSMP). One of the key goals of a WSMP is to assess available capacity in the existing water system and identify needed improvement projects for the CIP. The condition information documented in this memo will be used to identify non-capacity driven improvements and to prioritize the recommended CIP.

Water System Overview

Forest Grove has provided water to its citizens for over 100 years. Some of the original water system structures, built in 1912, are still in operation. Currently water is supplied from two sources, the Joint Water Commission (JWC) Water Treatment Plant (WTP) and the City's WTP. The JWC WTP is a regional partnership which treats water from the Tualatin River, Barney Reservoir, and Hagg Lake. Water is delivered to the City from the JWC's Fern Hill storage reservoirs through a 24-inch diameter transmission main and the City's 10th Avenue Control Station. From the 10th Avenue Control Station, JWC supply flows through 368 Zone distribution mains to the 5 million-gallon (5.0 MG) Reservoir.

The City's WTP treats water from the Gales Creek watershed which is piped to the WTP site through a 16-inch diameter raw water transmission main (RWTM). Treated water is stored in the 5.0 MG Reservoir at the WTP site. The 5.0 MG Reservoir supplies the 368 Zone which serves most City water customers.

Higher-elevation customers (540 Zone) in the northwest of the City are served from the David Hill Reservoir and the Watercrest and David Hill Pump Stations. Both pump stations draw suction supply from 368 Zone distribution mains and pump through 540 Zone distribution mains to fill the David Hill Reservoir. The 435 Zone is served from the 540 Zone through multiple pressure reducing valves (PRVs) throughout the distribution system.

JWC Supply Facilities (City owned)

10th Avenue Control Station

Description

The 10th Avenue Control Station is comprised of:

- 18-inch and 8-inch diameter parallel Cla-Val control valves with hydraulic pilot system for pressure control and solenoid-driven flow control
- ultrasonic flow metering equipment
- fluoride injection equipment including a metering pump, with flow paced controls, and in-line analyzer

The control station is housed in a cinder block building on the south side of Forest Grove at the dead end of 10th Avenue west of Elm Street. This section of industrial-zoned land along 10th Avenue forms a wedge between Highway 47 and the Portland & Western Railroad (PNWR) tracks. The station building fills most of the City-owned property it sits on. The property is fenced on three sides up to the building face with chain link fence topped with barbed wire. Vehicle access and parking is along 10th Avenue.

Currently the station control valves are operated based on flow set-points which are adjusted by operations staff at the City's WTP depending on water production at the City's WTP and customer demand. Pressure control through the 10th Avenue Control Station is set at 82 pounds per square inch (psi). In case of a power failure, the station will default to pressure control. Both the City and the JWC monitor flow at the 10th Avenue Control Station through connections to the meter from their respective Supervisory Control and Data Acquisition (SCADA) systems.

Condition and Operation Observations

Per City staff, flow control is disengaged via a switch on the control panel.. This has not been an issue for City staff who report flow control has been an effective way to manage JWC supply.

There is no back-up power on-site at the station.

There is no sanitary sewer connection at the existing station. The lab sink at the site currently drains to a stormwater drainage way behind the building. Although only very small amounts of

treated water may be discharged from the sink the need for a sanitary sewer system connection should be evaluated.

City Water Supply Facilities

Clear Creek Watershed Raw Water Transmission Main (RWTM)

The RWTM is a 16-inch diameter concrete cylinder pipe (CCP) constructed in 1963. This transmission main runs approximately 7.8 miles from the City's Gales Creek watershed intakes to the City's WTP. The RWTM alignment crosses active agricultural fields and passes through ancient landslide areas along Soda Springs Road near the City's intakes. **Figure 1** at the end of this memo illustrates ancient landslide mapping from the Oregon Department of Geology and Mineral Industries (DOGAMI) for the area around the RWTM alignment.

City water system operators report that the RWTM continues to function effectively if the cement mortar coating is not cracked. Exterior coating cracks appear to lead to pipe failure as the helically wound reinforcing wire unravels. This is consistent with water industry research on the most common failure modes for CCP mains. City staff have observed cracking of the exterior cement mortar coating on the RWTM due to assumed ground movement in a known slide area between the Clear Creek crossing and Soda Springs Road. This section of pipe, where most recent main breaks have occurred, is shown inside the red circle on **Figure 1** at the end of this memo. RWTM repairs are complicated by limited access for area homeowners along the narrow Soda Springs Road during a repair.

Prior to 1994, customers in the Gales Creek Service Area were served directly from the RWTM. Leaks in the RWTM have also occurred at abandoned service connections. These service connections used cast iron threaded connectors which were abandoned in place.

Raw Water Booster Pump Station

The City's Raw Water Booster Pump Station boosts flow in the gravity-fed RWTM as needed to supply the City's WTP under peak demand conditions. The station, housed in an underground vault along Gales Creek Road next to Forest Glen Park, was connected to the existing RWTM in 1979 by cutting a tee into the 16-inch diameter CCP main. In the summer of 2018 a leak was discovered in the connection between the pump station and the 16-inch diameter CCP main. The connection was repaired in September 2018. This repair was complicated by a large block of concrete poured over the connection during construction in 1979. The station is otherwise in good working condition.

City Water Treatment Plant (WTP)

Detailed analysis of City treatment processes and equipment is outside of the scope of the WSMP and this memo. City WTP staff state that a comprehensive WTP Facility Plan is needed to address the age and condition of multiple facilities on the WTP site and some operational issues such as

the City's current dewatering process for residual solids. Four key items noted by City staff are described in the following paragraphs.

Age and Condition Issues

- ***Existing sedimentation basin*** was the City's first storage reservoir constructed in 1912 and may have exceeded its life expectancy.

- ***Transfer pumps*** which boost flow from the sedimentation basin up the hill to WTP filters have had issues with motor lifespan. Motor failure may be exacerbated by weather exposure as the pumps are outside with no cover. The City intends to explore constructing housing over the existing pumps.

- ***Existing house on-site*** is a former single-family residence on the WTP site that is currently used for storage. A different building or interior configuration would be more useful to City staff for storage at the WTP site.

Waste stream dewatering system

The City's current dewatering and solids disposal process requires purchase of perlite for processing which is later disposed of. Disposal of solids requires one to two trips weekly to the landfill, which requires significant staff time. Dewatering equipment is sited within the WTP shop making the space unusable for other maintenance needs.

5.0 MG Reservoir

The City's 5.0 MG Reservoir is a reinforced concrete, hopper bottom, buried rectangular tank built in 1948. The tank is divided into two equally-sized cells (north and south) to provide operational flexibility if needed for maintenance. The tank is relatively shallow with a large 304-foot by 152-foot footprint.

City staff have observed significant increased drainage flow from the reservoir's foundation perimeter drain indicating a potential leak in the tank. As of October 2018, City staff have narrowed the leak area to the discharge sump of the north reservoir cell. City staff have observed voids in the concrete tank wall left by what appear to be decomposing wooden form stakes left from initial construction. Small leaks at these stake sites may be an on-going issue as any remaining stakes degrade.

Due to the tank's construction type and age, it is anticipated that the reservoir may be vulnerable to failure during a seismic event. More detailed evaluation of seismic performance is anticipated in the City's 2018 water system seismic vulnerability assessment, currently underway.

540 Zone Pump Stations

Watercrest Pump Station

The Watercrest Pump Station, across Watercrest Road from the WTP and 5.0 MG Reservoir site, has a single pump housed in a partially-buried concrete building. The building is sited on a narrow un-fenced City-owned property between Watercrest Road and neighboring residential properties. The existing pump is not equipped with a variable frequency drive (VFD). Water is pumped through the distribution system to the David Hill Reservoir. This station is the primary supply to the David Hill Reservoir.

David Hill Pump Station

The David Hill Pump Station supplies the David Hill Reservoir through 540 Zone distribution mains from 368 Zone distribution. The station has two pumps without VFDs which run lead-lag based on the David Hill Reservoir level. The station equipment and pumps have not been replaced since their installation in 1985 when the pump station was constructed. The station is infrequently operated because Watercrest Pump Station provides primary supply to the David Hill Reservoir since Watercrest was upgraded in 2006. The David Hill Pump Station is housed in a brick building with a membrane roof installed in 2018. City staff noted that the slope behind the structure may be steeper than recommended without a retaining wall and may fail during a seismic event. The station property is un-fenced.

David Hill Reservoir

The David Hill Reservoir is a 96-foot by 76-foot partially buried reinforced concrete tank built in 1985. The tank sets the hydraulic grade for the 540 Zone and provides storage for the 540- and 435 Zones. City staff report that there is currently no cleaning or inspection schedule for the tank. City staff were not aware of any recent interior inspection. The Watercrest and David Hill Pump Stations are not configured to serve customers constant pressure if the reservoir were taken out of service.

The reservoir is located on a small parcel of City-owned property within an active Christmas tree farm. A drainage easement within a natural drainageway on the tree farm property provides the flow path to an outfall at David Hill Road for drainage from the reservoir site, the foundation perimeter drain, and the tank's emergency overflow. City staff note that there have been issues maintaining a clear drainage way with neighboring tree farm activity. City staff suggested that piping all drainage and runoff from the site through the existing easement may be a solution for maintaining a clear flow path. City staff would also consider improving site grading around the reservoir to encourage drainage.

Gales Creek Service Area

The Gales Creek Service Area serves customers northwest of the City, outside the Urban Growth Boundary (UGB). These customers were historically served directly from the RWTM. Anticipating legislative amendments to the federal Safe Drinking Water Act, a 6-inch diameter Class 160 PVC distribution main was installed in 1996 parallel to the RWTM alignment to serve treated water to customers in the Gales Creek Service Area. Water is supplied from the David Hill Reservoir and 540 Zone distribution mains through the Gales Creek PRV.

Portions of the Gales Creek Service Area distribution piping are unmapped and are believed to cross private property, including active farmland, without easements. The Service Area is operated at relatively high pressure, approximately 90 psi, to overcome head loss through the small diameter distribution mains and supply adequate service pressure to the last customers on the line who are also at the highest elevations.

City staff report significant water loss from assumed leaks within the Gales Creek Service Area distribution mains. City distribution system operators perform a monthly water audit of the Service Area by comparing metered flows through the Gales Creek PRV station with Gales Creek customers' metered consumption. Based on a water audit completed by City staff for this service area, water loss is currently estimated at approximately 21,500 gallons per day (gpd). Based on recent flow readings from the Gales Creek PRV station, water loss may be as high as 50 percent of all Gales Creek Service Area flow.

Conclusion

Based on discussions with Forest Grove staff and observations during site visits in September 2018, some key condition and operational issues with City water facilities emerged. They are summarized as follows:

- Landslide vulnerability contributing to leaks in the RWTM
- Need for a comprehensive WTP Facility Plan to include:
    - Structural assessment of existing sedimentation basin and 5.0 MG Reservoir, some of which may be addressed in current seismic vulnerability assessment
    - Waste stream dewatering system evaluation – current method is labor intensive
    - Storage and shop space
- 5.0 MG Reservoir seismic vulnerability
- David Hill Pump Station equipment upgrade and potential building/site seismic vulnerability
- David Hill Reservoir clear drainage way issues from adjacent agricultural activity; need for on-going maintenance and inspection plan
- Gales Creek Service Area significant water loss – unmapped distribution piping makes addressing leaks challenging

APPENDIX F
HYDRAULIC MODEL SOFTWARE SELECTION, MURRAYSMITH, 2018

Memorandum

Date:	June 4, 2019
Project:	18-2197.1001 - City of Forest Grove – Water System Master Plan
To:	Mr. Rich Blackmun, P.E. City of Forest Grove
From:	Brian Ginter, P.E. Heidi Springer, P.E. Murraysmith
Re:	Hydraulic Model Software and Evaluation

Introduction

The purpose of this memorandum is to document a brief evaluation of the two industry-leading hydraulic model software programs and provide a recommendation to the City of Forest Grove (City) regarding which software the City's water system hydraulic model should be updated and maintained in, as part of the current Water System Master Plan development. In addition, this memorandum will provide information to the City to inform a decision to purchase the software for use by City staff.

Background

There are many options available for network analysis hydraulic modeling software and different modeling platforms are better for some clients based on the background of the users. The pipe flow hydraulic modeling industry has standardized on the hydraulic engine EPANet. This was developed by the United States Environmental Protection Agency (US EPA) to perform water quality analysis and includes a hydraulic engine that allows extended period simulation (EPS) analysis. Throughout the industry, and especially in the Pacific Northwest, there are currently two primary software platforms used by public agencies and engineering consultants – WaterGEMS by Bentley and InfoWater by Innovyze.

The City's current hydraulic model is WaterGEMS by Bentley and was the used for 2000 and 2010 Water Master Plans.

Software Comparison

The table below presents a brief comparison of the two software platforms relative to the base EPANet software available as shareware from US EPA.

Table 1
Modeling Software Comparison

	EPANet	WaterGEMS	InfoWater
Hydraulic Engine	EPANet	*EPANet	*EPANet
Software Vendor	US EPA	Bentley	Innovyze
Platform	Stand-Alone	ArcGIS	ArcGIS
GIS Import/Export	No	Yes	Yes
ODBC Connectivity	No	Yes	Yes
Ability to Subset Model	No	Yes	Yes
Overall Functionality	Low	High	High
Report Quality Graphics	No	Yes	Yes
Complexity of Use	Low	High	High
Cost (3000 pipes)	Free	$17,597	$7,355
Maintenance	Free	$4,224/year	$1,475/year
Technical Support	Minimal	Excellent	Excellent

Note: *Modified from US EPA shareware version

As indicated in the table, both WaterGEMS and InfoWater provide comparable functionality and support. Costs for software purchase and maintenance of WaterGEMS is significantly higher than a comparable license for InfoWater.

Bentley WaterGEMS also offers a pre-paid monthly licensing package where the user makes a $5,000 deposit to start and is charged $822 per month against that balance for each calendar month when the software is used regardless of the number of uses in that month.

It is Murraysmith's experience that the pool of hydraulic modelers with InfoWater proficiency in the Portland Metro area is larger than the pool of those proficient in WaterGEMS. Converting the City's model to InfoWater will open rather than narrow the City's options for future consultants to perform water modeling work. At Murraysmith, a portion of the cost for the annual maintenance of either software platform is incorporated into the respective project costs when the software is necessary for the successful completion of a project.

Murraysmith Experience with Software

Murraysmith maintains active licenses for both software platforms. Since approximately 2005, we have seen a significant number of our clients select the Innovyze InfoWater software platform. As a result, approximately 95 percent of the current active hydraulic models we maintain are in InfoWater. In order to allow for multiple models to be operated simultaneously across multiple project teams, Murraysmith maintains five InfoWater licenses and only one WaterGEMS license.

Due to the high volume of InfoWater models currently maintained by our firm, our hydraulic modeling staff, while proficient with both software platforms, are able to work more efficiently with the InfoWater platform and reduce the level of effort required because it is the more commonly used software amongst modelers.

Considerations for City Purchase of Hydraulic Modeling Software

Murraysmith understands that the City is considering the purchase of hydraulic modeling software for on-going internal use by City staff. Based on our understanding of City staffing levels and experience with hydraulic modeling, it is our recommendation that the City not purchase the software for internal use. The key reasons for this recommendation are:

- Murraysmith is not aware of a similar sized utility in Oregon that currently maintains their own hydraulic model.
- Based on our experience with training and maintaining hydraulic modeling expertise and our coordination with the few larger utilities (City of Gresham, Portland Water Bureau, Springfield Utility Board and Eugene Water & Electric Board) that do maintain water system hydraulic models internally, a utility should not consider in-house model maintenance unless the following conditions can be met:
    - Hire licensed engineering staff with at least 2 years of hydraulic modeling experience
    - Dedicate at least 30 percent time for one full-time employee (FTE) to maintain model, including routine updates, and continuing hydraulic model education and training

Recommendations

Based on the brief evaluation presented above, Murraysmith recommends the following:

- Convert the existing water system hydraulic model to Innovyze InfoWater as part of the Water System Master Plan project. The process of model update and calibration presents an opportunity to efficiently complete the conversion as part of comprehensive model update and calibration efforts.

- Continue to utilize consultant resources for model updates and hydraulic analyses. The City is not likely to re-coup the cost of software purchase, maintenance agreement, and staff resources given the anticipated volume of hydraulic modeling the City water system requires. While the two software platforms are very similar, it is Murraysmith's experience that InfoWater is more commonly used in the Portland Metro area resulting in a larger pool of hydraulic modelers with higher proficiency levels than those seen with WaterGEMS. Converting the City's model from WaterGEMS to InfoWater would also expand the City's capability to work with future consultants for modeling work and reduce the required level of effort for the modelers. This reduction in the level of effort could potentially result in project associated cost savings for the City depending on the nature and complexity of the modeling work being performed.

APPENDIX G
HYDRAULIC MODEL CALIBRATION MEMO, MURRAYSMITH, 2020

Technical Memorandum

Date: February 11, 2020

Project: Forest Grove Water System Plan (18-2197)

To: Richard Blackmun, PE
City of Forest Grove

From: Heidi Springer, PE
Claire DeVoe, EIT
Murraysmith

Re: Hydraulic Model Calibration

Background

Murraysmith is currently supporting the City of Forest Grove (City) with the update of their Water System Master Plan (WSMP) and hydraulic model. The City's prior hydraulic model used Bentley WaterGems software and was calibrated in 2010 by HDR. This model was converted to Innovyze InfoWater software by Murraysmith and updated with new piping based on GIS mapping provided by the City. Calibration of the Forest Grove model will be completed for a steady state simulation.

Calibration is one of the most important tasks in developing a hydraulic water system model. The goal of the calibration is to represent real-world conditions in the model including demands, pressures, fire flows, and system operations. By collecting flow and pressure data at key points across the system, the model can be validated and used with higher confidence for future planning purposes.

Steady state calibration involves static pressure testing and hydrant flow testing. First a static pressure is measured at a hydrant. Then, a nearby hydrant is opened to stress the distribution system's ability to deliver flows while maintaining pressure. The resulting pressure drop is manually recorded and used with system boundary conditions, such as reservoir water levels at the time of the test, to verify system operations and pipe friction factors in the model. These hydrant flow tests can often identify inaccuracies in PRV settings, faulty valves, elevation errors, poor demand distribution, or connection issues in the model.

Once the model is calibrated, each pressure zone is given a confidence level using the criteria shown in **Table 1**. Static error is measured as a percent pressure difference between model results and field results ([model value – field value]/[field value]). A negative sign (-) indicates that the

model pressure is lower than the field test, and a positive sign indicates that the model is over estimating pressure compared to test data. Calibration results for the fire flow tests are expressed as a difference in the pressure drop recorded in the field and the pressure drop reported from the model simulation ([model static – model residual] - [field static – field residual]). Because the reported result is based on comparing pressure drop as opposed to actual pressure, any error in the static calibration is not carried over to the fire flow calibration. Confidence levels help inform future modeling efforts with the level of accuracy to be expected.

Table 1
Calibration Confidence Levels

Confidence Level	Static Test Percent Error	Residual Fire Flow Pressure Difference
High	<5%	< 10 psi
Medium	5 to 10%	10 to 20 psi
Low	>10%	> 20 psi

1. Percent error and pressure difference represent absolute value difference between field and model results.

Model Conversion and Update

The City's prior WaterGems water system hydraulic model was converted into Innovyze InfoWater software. The prior model's junctions, junction elevations, pipe geometry, pipe lengths, and roughness coefficients were preserved from the WaterGems version. New piping and junctions were added per the updated GIS data provided by the City. Pipe roughness coefficients for new pipes were set at C = 135 which is consistent with the existing model and within the typical range of values for new ductile iron pipe.

Model Elevations and Vertical Datums

Junction elevations were set using contour data available from the regional government Metro's Regional Land Information System (RLIS). The RLIS contours use the 1988 North American Vertical Datum (NAVD 88). After initial model set-up and calibration were complete, it was learned that the City uses a local vertical datum, the Forest Grove Vertical Datum (FGVD) to define water facility elevations. The FGVD is 4 feet lower in elevation than the NAVD 88 datum used to assign junction and pressure reducing valve (PRV) elevations in the model.

The effect of this datum difference, between reservoirs and junctions in the modeled distribution system is that pressures appear slightly lower than field measured conditions. This difference is within the margin of error (+/- 5 pounds per square inch (psi)) of the model and is thus unlikely to significantly impact hydraulic analysis. Junction elevations in the model were adjusted to match the FGVD.

System pressures simulated in the model were checked with field pressures measured during fire hydrant flow testing. There was no significant difference in calibration confidence after the elevation updates.

Pump Curves

Pump curves were not available for distribution system booster pump stations Watercrest or David Hill. Pump curves were approximated using a generalized model pump curve created from a single control point provided by the City. Pump on/off controls were set based on City staff comments. Generally, the single pump at Watercrest Pump Station operates to fill the David Hill Reservoir based on the tank water level. The David Hill Pump Station rarely operates. The two pumps in this station operate lead-lag.

Pressure Reducing Valves (PRVs)

PRV settings were updated from field-verified data provided by the City.

JWC Supply

The 10th Ave Control Station provides supply from the Joint Water Commission (JWC) through a flow control valve/pressure reducing valve (FCV/PRV) that is manually operated when supplemental supply to the City is required. The station can operate under either flow or pressure control. Per City comments, the valve currently operates under flow control and responds to a fire by switching to pressure control. The modeled flow control valve was set at 1,000 gallons per minute (gpm) when active, consistent with data provided during calibration flow testing.

The City installed a pressure logger at the intersection of 19th Avenue and Oak Street, and recorded system pressure for the month of September 2019 at 30-minute resolution. This data was used to verify approximate system pressures. If the City is planning to use the model in the future for very detailed analysis, it would be valuable to look at pressure logging data near the JWC connection in addition to system boundary conditions at the time the data is logged, to understand how the hydraulic grade in the 368 zone is influenced by the 10th Avenue Control Station control valve. This calibration refinement is beyond the scope of this project and is not expected to significantly influence the capital improvement program (CIP) recommendations of this WSMP. It is recommended that the City does not pursue this further at this time.

System Demands

Modeled system demands were also updated. Geocoded consumption data from the City's utility billing system was used to distribute average day demands (ADD) and maximum day demands (MDD) to the closest model node in the correct pressure zone. Nodes close to valves, reservoirs, or pump stations were not included in this set of demand model nodes. Consumption data was only available on a per-account basis by month. Therefore, the max month distribution (August) was used to approximate the MDD distribution.

The distributed demand sets were then scaled so the total system-wide demand matched the 5-year average from 2013-2017 for ADD and MDD, calculated from supply data and summarized in million gallons per day (mgd) **Table 2**.

Table 2
Existing System Demands

Demand Set	System Demand (mgd)
ADD	3.0
MDD	5.7

Field Testing

On November 13th and 14th, 2018, representatives from the City and Murraysmith performed approximately 20 field tests, distributed across the system and under various supply conditions. On February 13th, 2019, two additional tests were performed to verify calibration of the far eastern reaches of the 368 Zone due to leaking test equipment during the November tests.

Two sets of tests were performed in the 368 Zone to quantify the effects of the City's two water supplies; JWC supply from the 10th Ave Control Station in the south and supply from the City's 5MG Reservoir at the Water Treatment Plant (WTP) site to the north. First, a set of 5 tests were performed with JWC supply. Then the JWC supply was switched off and the same 5 tests were performed with only supply from the City's 5MG Reservoir.

During field testing, a leak in one of the pressure measurement devices was discovered. Several tests were rerun with various City, Murraysmith, and Fire Department instruments to improve accurate results. As described previously, additional tests were performed in February to improve calibration confidence.

Calibration Results

In general, the model calibrated with a medium level of confidence. In all zones, the model typically overpredicts static pressures. On average, the model underestimates the pressure drop caused by a fire flow. Table 1 was used to rate the confidence level of each zone, in addition to data variance, supply path sensitivity, and reliability of model convergence. **Table 3** summarizes the calibration results by zone and **Figures 1 and 2** map the modeled static pressure and fire flow results. **Table 4** includes a complete list of results for each calibration flow test.

Table 3
Calibration Results Averaged by Zone

Zone	Static Pressure Percent Error	Residual Fire Flow Pressure Difference (PSI)	Confidence Level
368 - Average	5%	-5	Medium/High
368 - JWC Supply	5%	-4	Medium/High
368 - WTP Supply	5%	-6	Medium/High
435	5%	-5	Medium/High
540	<1%	-5	High
Gales Creek[1]	N/A	N/A	N/A
435 – Valley Crest Way PRV[2]	N/A	N/A	N/A

1. No flow tests recorded in the Gales Creek Service Area.
2. Small subzone supplying <20 homes. No flow tests conducted here.

Table 4
Calibration Results

Test No.	Pressure Zone	Static Pressure Percent Error	Residual Fire Flow Pressure Differential
1	540	-0.7%	-6.8
2	540	2.9%	-5.1
5	540	-1.4%	-3.1
3	435	6.5%	-6.4
4	435	3.4%	-3.8
7	435	6.4%	-2.6
9JWC	368	3.4%	-2.3
10JWC	368	5.8%	-4.0
12JWC	368	5.5%	-7.8
13JWC	368	2.7%	-2.9
14JWC	368	1.9%	-9.0
17JWC	368	8.1%	9.7
18JWC	368	4.8%	2.8
6	368	7.1%	-1.6
8	368	5.9%	-4.5
9	368	4.8%	-6.3
10	368	9.6%	-5.0
11	368	5.1%	0.1
12	368	5.0%	-3.7
13	368	4.7%	-0.1
14	368	2.3%	-15.4
15	368	3.1%	1.4
16	368	5.2%	-4.9

1. Test 7 would not converge at listed flow rate. Results shown are for a flow rate of 1100 gpm (127 gpm less than field recorded). Test 7 not included in 435 Zone Average in Table 3.

Calibration Notes

Operating Assumptions

The following additional assumptions were made during calibration:

System Demands - For calibration, the ADD set was scaled to an average (2013-2017) November demand of 1,700 gpm.

Pump Station Operations – Throughout testing, water levels in the David Hill Reservoir remained within an operating range where only the Watercrest Pump Station would turn on. Therefore, the David Hill Pump Station was assumed off for all tests. This is consistent with City comments.

Pressure Reducing Valves – PRVs supplying the 435 Zone and the 368 Zone were field tested in December 2019 by City staff and updated in the model during review. The 2-inch valve at the Lavina PRV station was adjusted up by 1 psi from City values to improve model convergence.

Reservoir Levels – Water levels in both City reservoirs were not available for all tests. Water level in the David Hill Reservoir is measured in feet from the reported base of the tank up to the water surface. Water level in the 5MG Reservoir is measured from the shelf located at an elevation of 358.75 feet to the water surface. The David Hill Reservoir was approximated at 15.75 feet for the tests in the 368 Zone. The 5MG Reservoir was approximated at 7.5 feet for tests in the 435 and 540 Zones.

JWC vs WTP Supply to the 368 Zone

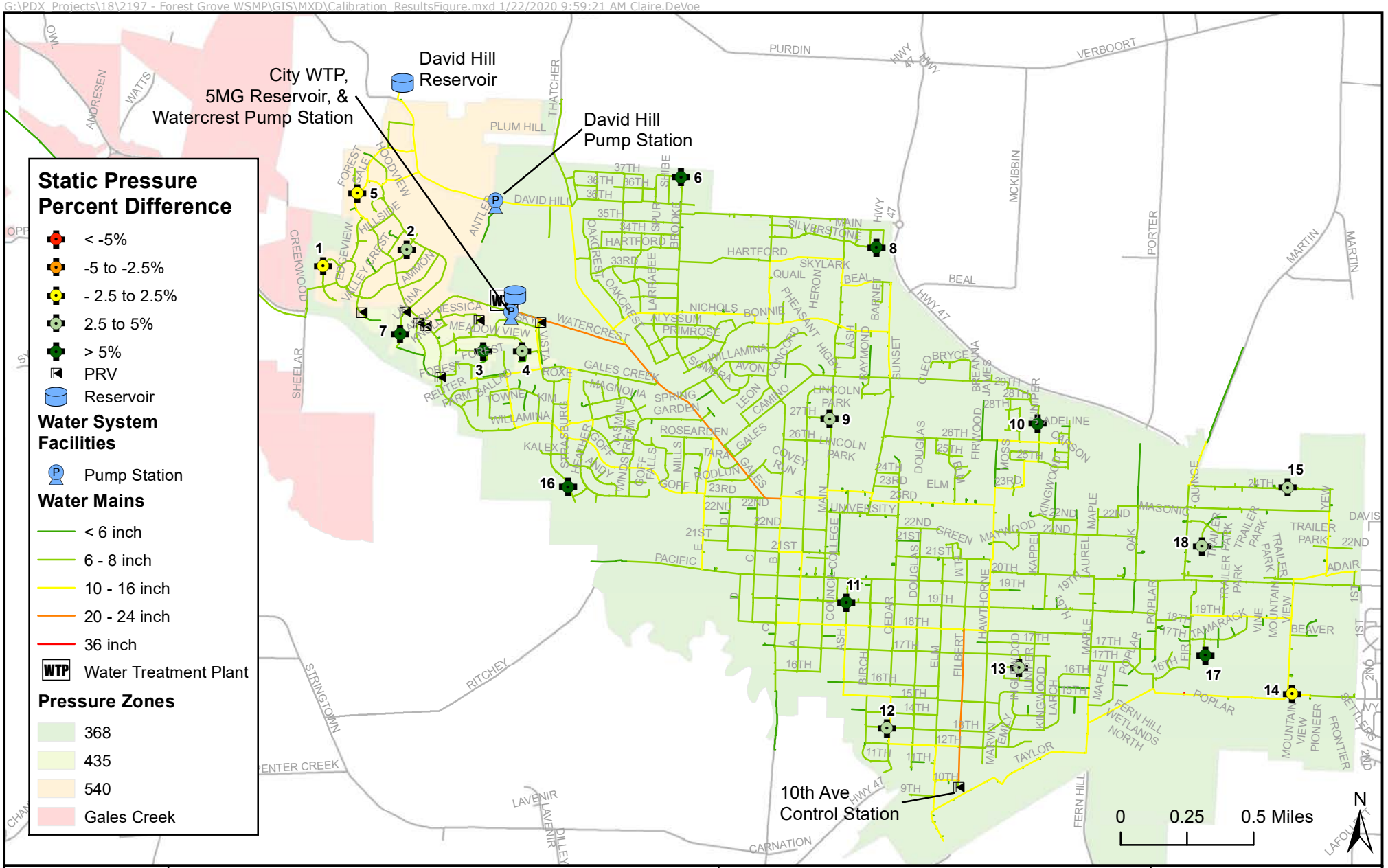
Several tests in the 368 Zone were performed under both supply conditions – condition 1: supply from both the JWC and the City's 5MG Reservoir, and condition 2: supply from only the City's 5MG Reservoir. There was not a significant difference in calibration confidence between the two supply conditions. **Figures 1 and 2** show the results with supply from only the 5MG Reservoir, except for tests 17 and 18 which show results from JWC supply. In general, the model more accurately predicts fire flow pressure drops without the JWC active.

As stated earlier, if the City would like to use the model for very detailed analysis, then additional calibration may be warranted. This work is beyond the scope of this project and is not recommended at this time.

Pump Station Operations

The pump curves for both the Watercrest and David Hill Pump Stations were not updated in this calibration. While the system performed well with the Watercrest Pump Station operating at a control point and default pump curve, it is recommended that a calibration test be performed for all pumps if specific pump operation is required for additional scenarios.

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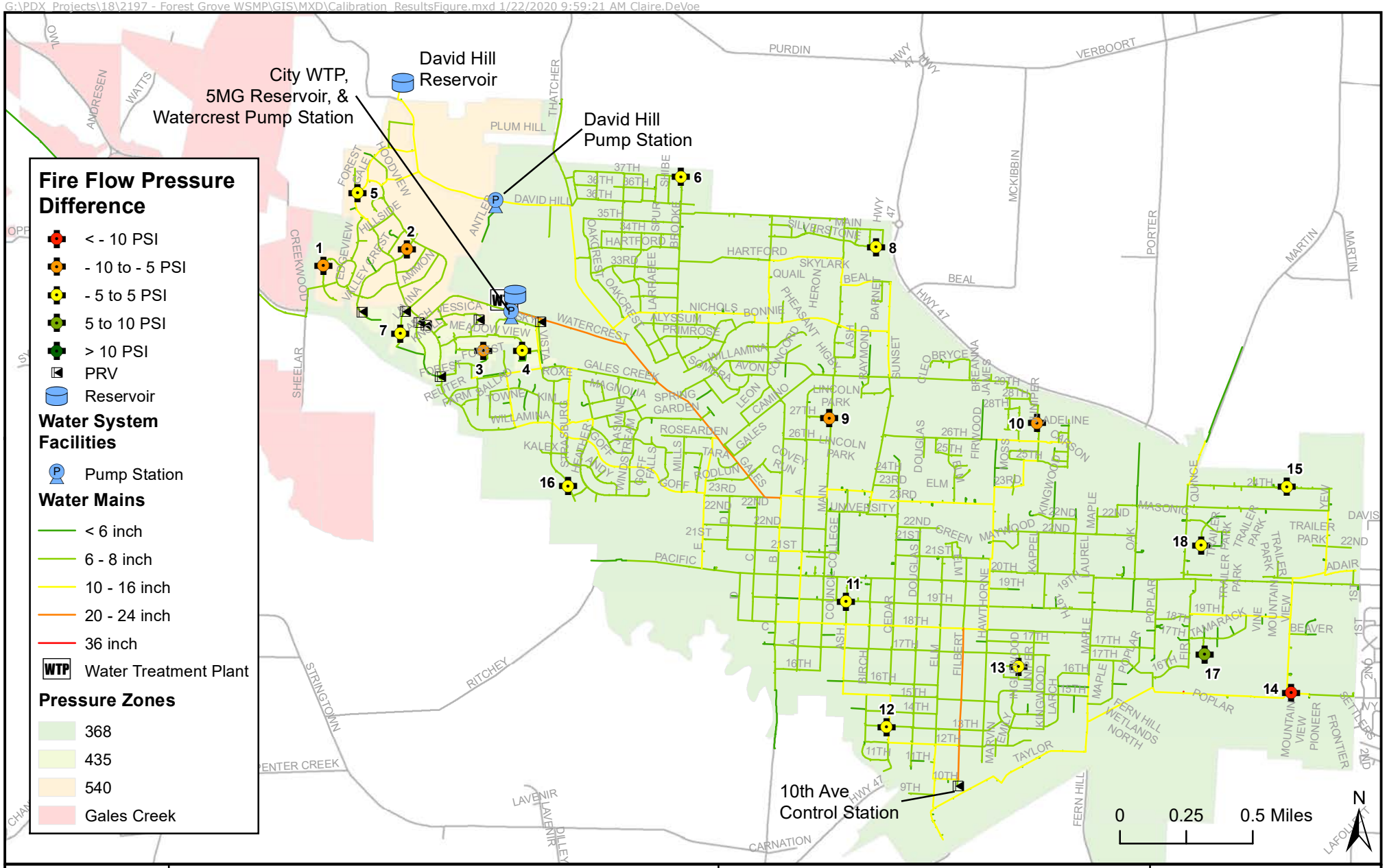
City of Forest Grove
Water System Master Plan

Figure 1
Hydraulic Model Calibration
Static Pressure

murraysmith

FOREST GROVE OR

February 2020 18-2197



City of Forest Grove
Water System Master Plan

Figure 2
Hydraulic Model Calibration
Fire Flow Results

APPENDIX H
WATER SYSTEM SEISMIC RESILIENCY PLAN, INFRATERRA, 2020

Draft Final Report

City of Forest Grove

Water System Seismic Resiliency Plan



EXPIRES: 12/31/2020

Ahmed Nisar, PE
Principal
InfraTerra, Inc.
September 15, 2020

FOREST GROVE OREGON
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InfraTerra

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LIST OF ABBREVIATIONS AND ACRONYMS

$(N_1)_{60}$	Corrected Standard Penetration Resistance
3D	Three dimensional
ALA	American Lifelines Alliance
CCP	Concrete Cylinder Pipe
CES	Canterbury earthquake sequence
CI	Cast Iron
CMU	Concrete Masonry Unit
CPT	Cone Penetrometer Test
CRR	Cyclic resistance ratio
CSR	Cyclic stress ratio
CSZ	Cascadia Subduction Zone
DI	Ductile Iron
DOGAMI	Oregon Department of Geology and Mineral Industries
EMAC	Emergency Management Assistance Compact
FEMA	Federal Emergency Management Agency
FFE	Fire Following an Earthquake
FGFR	Forest Grove Fire & Rescue
GIS	Geographic Information System
GPM	Gallons per minute
JWC	Joint Water Commission
MG	Million Gallon
MGD	Million gallons per day
M_w or M	Moment Magnitude
ORP	Oregon Resilience Plan
ORWARN	Oregon Water/Wastewater Agency Response Network
OSSPAC	Oregon Seismic Policy Advisory Commission
PGA	Peak Ground Acceleration
PGD	Permanent Ground Deformation
PGV	Peak Ground Velocity
PNW	Pacific Northwest
PRCI	Pipeline Research Council International
PVC	Polyvinyl Chloride
Qal	Quaternary alluvium (sediments occurring in flood plains)
Qs	Quaternary Silt
RR	Repair Rates
RWTM	Raw Water Transmission Main
S_1	Spectral Acceleration at 1.0 Second
SLIDO	Statewide Landslide Information Database for Oregon

SPT	Standard Penetration Test
SRP	Seismic Resiliency Plan
S_s	Spectral Acceleration
TGD	Transient Ground Deformation
TSoR	Target States of recovery
USGS	United States Geological Survey
WCCCA	Washington County Consolidated Communications Agency
WTP	Water Treatment Plant

EXECUTIVE SUMMARY

Recent studies show that there is a 16 percent to 22 percent probability of a major earthquake on the Cascadia Subduction Zone (CSZ) in the next 50 years. Such an earthquake could impact the entire Pacific Northwest (PNW) and Northern California. Recognizing this risk, the Oregon House of Representatives passed House Resolution 3 in 2011, which directed the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) to prepare an Oregon Resilience Plan (ORP). The purpose of ORP is to help agencies set internal policy direction that will protect lives and maintain economic and commercial activity following a Moment Magnitude 9.0 (M9) CSZ earthquake and tsunami.

The City of Forest Grove (City), located approximately 40 miles from the Oregon coast, will be significantly impacted by a major earthquake on CSZ. The purpose of this study is to assess the seismic performance of the City's water system in an M9 earthquake and provide recommendations for improving the reliability of water supply to its approximately 25,000 residents. While the system could be impacted by an earthquake on the local Gales Creek fault, the likelihood of such an earthquake is significantly lower than the CSZ M9 earthquake. Therefore, consistent with ORP, the M9 earthquake on CSZ was selected for the development of Water System Seismic Resilience Plan (SRP). An overall time frame of 50 years is selected to implement the plan and improve water system performance to meet or exceed the performance goals outlined in ORP.

To develop the Water System SRP, the project team, including InfraTerra[1] and City[2] staff participated in a workshop to identify critical components of the City's water system to serve as the water system backbone. This SRP is based on the premise that the water system backbone reliably provides water throughout the City to meet the most critical needs in the aftermath of the M9 earthquake while damage to the remainder of the system is addressed. The Water System SRP selected the ORP's performance goal for the backbone to be 80 to 90 percent operational within 24 hours of the earthquake, and the entire system to be 80 to 90 percent operational approximately within 1 month after that.

The identified backbone system is shown in Plates E1 and E2, and includes the water treatment plant, 9.1 miles of raw water transmission main (RWTM), the 1.6 mile long 24-inch Joint Water Commission (JWC) finished water transmission lines, and 13.4 miles of distribution pipelines. The identified backbone distribution pipelines include

[1] Ahmed Nisar, Mike Greenfield and Charles Scawthorn

[2] Rob Foster, Rich Blackmun, Derek Robbins, Rick Vanderkin, Brian Dixon, and Dave Nemeyer

only existing pipelines. Backbone pipelines were prioritized such that water can be transported to (in descending priority) the City's central district, industrial district in the Northeast of town, and the loop up to David Hill Reservoir. Backbone pipelines with highest priority were identified as first-tier and the remaining as second-tier. In addition to the main water supply source from the Clear Creek watershed, the City supplements its water from the Joint Water Commission (JWC) water treatment plant. Seismic assessment of the assets owned by the JWC partners, except the 24-inch JWC Transmission Line, was outside of the scope of this study.

The estimated shaking from the M9 earthquake could trigger landslides in the Clear Creek watershed and soil liquefaction in many of the low-lying areas within the City. Much of the City's water transmission and distribution system has seismically vulnerable cast-iron and concrete cylinder pipes that are especially susceptible to damage from earthquake-induced ground deformations caused by liquefaction and landslides. It is estimated that there could be over 50 leaks and/or breaks in the backbone system and possibly a couple hundred leaks or breaks in the non-backbone water distribution system. The study has also identified potential seismic deficiencies in the City's 5 million gallon (MG) Water Treatment Plant (WTP) reservoir.

In its current condition and with limited internal resources, it is estimated that it will take about 2 weeks to 1 month following the M9 earthquake for the City to recover to 90 percent backbone operation. The entire system recovery to 90 percent level is estimated to be about 3 to 6 months. Due to the regional impact of the M9 earthquake, material and repair resources support from surrounding communities would be in short supply and transportation routes may be limited.

To upgrade the water system so that it is fully operational shortly after a major earthquake would be costly. Recognizing the potential expense, two mitigation options are considered that, if implemented, would significantly improve the resiliency of the City's water system. Potential impact of transportation, power, and other supporting infrastructure for the restoration of water supply following the earthquake were beyond the scope of this study. Mitigation options discussed in this report were developed for an M9 CSZ earthquake. Research into the frequency of past fault ruptures and the activity of the local Gales Creek fault is still underway at the time of the writing of this report. A detailed assessment of a Gales Creek fault scenario was outside the scope of this study.

The two mitigation options include:

Mitigation Option 1 – designed to achieve 80 to 90 percent operational status for the backbone within 24 hours following an earthquake, requires the following capital improvement program (CIP) projects:

- Emergency pumping equipment to pump water from Gales Creek at the existing Stringtown Road Bridge
- Seismic upgrade of the RWTM between the Stringtown Road Bridge and the WTP, including retrofit of the Stringtown Road Bridge by Washington County, if needed (based on additional study)
- Pipeline replacement and re-route of approximately 500 feet of RWTM near Forest Glen Park
- Backup power supply to the existing raw water pump station
- Seismic upgrade or replacement of the 5 MG WTP reservoir
- Replacement of approximately 4.0 miles of backbone cast iron pipes
- Installation of isolation valve at strategic locations within the backbone system to minimize the risk of uncontrolled release of water from damaged pipelines

Mitigation Option 2 – (extension of Option 1) is designed to make substantial progress towards achieving the additional goal of 80 to 90 percent of the entire water distribution system being operational within 1 to 2 months. This option assumes that the City will have enough stockpile material and sufficient number of repair crews to bring the system back to its pre-earthquake levels in a reasonably short time. Since the City's repair resources are limited and regional recovery resources may become overextended following the M9 earthquake, Option 2 is designed to reduce the risk of system-wide pipeline breaks and allow the City resources to focus on critical repair and recovery efforts elsewhere.

Mitigation Option 2 recommends the following CIP projects:

- Completion of Mitigation Option 1 projects
- Replacement of approximately 0.8 miles of additional cast iron pipes within the second-tier backbone water distribution system
- Seismic upgrade of the 24-inch JWC finished water transmission line and adding flexibility to the pipeline at the 10th Avenue Control Station (assuming water supply from JWC will be available)
- Detailed evaluation of liquefaction hazard and structural response of the 10th Avenue Control Station to meet ASCE 41-17 Immediate Occupancy (structural and non-structural) performance level
- Backup power supply to the Watercrest Road and David Hill pump stations
- Structural seismic assessment of the David Hill reservoir
- Replacement of approximately 15.5 miles of non-backbone distribution system cast iron pipes and development of long-term non-cast iron pipeline replacement plan that considers liquefaction severity, corrosion, and age of pipelines
- Additional system wide installation of isolation valves at strategic locations within the system

We also recommend the City stockpile enough repair resources for 10 workdays worth of repairs, establishing material procurement protocols and on-call contracts with suppliers, develop repair protocols for rapid reimbursement from Federal Emergency Management Agency (FEMA) and develop an Emergency Management Assistance Compact (EMAC) program with the state of Oregon for receiving mutual aid from other states. We also recommend implementing non-CIP projects including emergency response training and protocols for City employees, programs to periodically evaluate and test emergency response equipment, and develop and maintain regularly updated utility maps with locations of pipeline repairs.

1.0 INTRODUCTION

InfraTerra, Inc. (InfraTerra) is pleased to submit the Water System Seismic Resiliency Plan (SRP) to the City of Forest Grove (City). This study was performed with InfraTerra as the prime consultant and SPA Risk, LLC (SPA), Greenfield Geotechnical, and Cascade GIS and Consulting (Cascade) as sub-consultants.

The purpose of this study is to (1) assess the seismic performance of the City's water system in a Moment Magnitude (M_w) 9.0 (M9) earthquake on the Cascadia Subduction Zone (CSZ) and (2) develop mitigation recommendations to improve the water system performance such that it meets or exceeds the performance goals of the Oregon Resilience Plan (ORP). For planning purposes, a 50-year time frame, same as that in ORP, was selected for the implementation of the identified mitigations options.

1.1 PROJECT TEAM

A comprehensive water system seismic assessment requires multi-disciplinary input, including geology and seismology; geotechnical, structural and pipeline engineering; system operations; and hydraulic response. Evaluation of a geographically distributed water system in a major earthquake requires an understanding of this multi-disciplinary problem to realistically assess system vulnerability, and to develop practical mitigation solutions.

The InfraTerra team included specialists with multidisciplinary background and past experience with water system seismic resiliency studies. They have developed resiliency plans for several major water systems including that of the City of Portland. The project team worked with City's staff to assess seismic resilience of the City's water system and develop recommendations to meet the overall objectives of the ORP.

1.2 BACKGROUND

CSZ, a 600-mile fault that runs from northern California up to British Columbia poses the most significant earthquake hazard to the City of Forest Grove, which is located approximately 40 miles from the Oregon coast. There have been 41 earthquakes in the last 10,000 years on CSZ with the most recent on January 26, 1700, with an estimated Magnitude of 9.0 magnitude. CSZ has not produced an earthquake since 1700. Recent studies show a 16 percent to 22 percent probability of an earthquake with Magnitude 8.5 or greater on CSZ in the next 50 years (Goldfinger et al., 2016). It is expected that such an earthquake could impact the entire Pacific Northwest (PNW) and Northern California. Geological evidence suggests that a rupture of the entire CSZ

can produce earthquakes as large as M9, and is generally used for most planning studies in the Pacific Northwest.

Recognizing the potential earthquake risk, in 2011, the Oregon House of Representatives passed House Resolution 3, which directed the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) to prepare an ORP to help agencies set internal policy direction to protect lives and maintain economic and commercial activity following an M9 earthquake and tsunami.

OSSPAC formed eight task groups to address various aspects of seismic risk. Of these, the Water and Wastewater Task Group estimated that under present conditions, it may take one month to a year to restore water service following an M9 earthquake. The task group identified a broad set of goals, referred to as target states of recovery (TSoR), for the time required to achieve different levels of service for water systems in Oregon.

The City may also experience earthquakes from nearby local earthquake sources. The most significant of which is the Gales Creek fault. Compared to the CSZ, the Gales Creek fault has low seismic activity. However, recent studies suggest that the fault may be more active than previously believed (Horst, 2018). These studies are still ongoing and have not reached definitive conclusions. Due to a significantly higher probability and region wide impact of an M9 earthquake, the present study adopted the ORP's TSoR goals to evaluate seismic performance of the City's water system.

1.3 STUDY TASKS

The Water System SRP study included the following tasks:

- **Earthquake hazard maps:** Develop seismic hazard maps consisting of ground shaking, liquefaction and earthquake-induced landslide hazards for the study area.
- **Backbone system performance:** Identify a backbone system consisting of key transmission and distribution system facilities, and assess its seismic performance.
- **Distribution system performance:** Assess seismic performance of distribution system not part of the backbone.
- **Mitigation measures:** Recommend mitigation projects, which if implemented over the next 50 years, will meet the ORP's TSoR goals.

1.4 REPORT ORGANIZATION

The Water System SRP includes an Executive Summary that describes the scope and purpose of the study, provides a brief description of the City's water system and its expected seismic performance, and lists recommended mitigations.

The remainder of this report is organized into 9 chapters as follows:

- **Chapter 1.0 - Introduction:** provides an introduction and overall objectives of the study
- **Chapter 2.0 – System Description:** includes a description of the City water system
- **Chapter 3.0 – Performance Objectives:** includes a description of ORP goals and TSoRs used for this study
- **Chapter 4.0 Seismic Hazard Maps:** provides a description and quantification of relevant seismic hazards
- **Chapter 5.0 – Seismic Vulnerability Assessment:** includes details of the seismic assessment and performance of water system components in an M9 earthquake
- **Chapter 6.0 – Post-Earthquake Repair:** presents a discussion on the City's available resources to perform post-earthquake repair and restoration following an M9 earthquake
- **Chapter 7.0 – Mitigation Options:** presents a range of potential mitigation options based on results of the vulnerability assessment
- **Chapter 8.0 – Recommendations:** provides a set of recommended mitigation projects
- **Chapter 9.0 – References:** includes a list of technical references

2.0 SYSTEM DESCRIPTION

The City's water system serves residential, commercial, and industrial consumers primarily within the current City limits. It serves a population of 23,555 and covers the service area shown in Figure 1 (full extent maps shown in Plate 1 and Plate 2).

The following sections describe the major elements of the water system.

2.1 WATER SUPPLY SYSTEM

The main source of raw water for the City is the Clear Creek watershed located about 8 miles north of the City's Water Treatment Plant (WTP). The water supply is supplemented by treated water from the Joint Water Commission (JWC) WTP located on Spring Hill Road south of the City.

2.1.1 CLEAR CREEK WATERSHED

The City owns 4,300 acres within the Clear Creek watershed that can provide as much as 3.7 million gallons per day (MGD) of raw water. Water from the watershed flows under gravity and is treated at WTP. A booster pump is located between the Clear Creek watershed and WTP, which is only operated when water demand exceeds the gravity capacity of the raw water transmission main (RWTM).

Within the watershed, the City has intake facilities on Clear Creek, Roaring Creek, Smith Creek, Deep Creek, and Thomas Creek. Figure 2 shows intake facilities at Deep Creek and Roaring Creek, facilities at other locations are generally similar. A typical river intake consists of a perforated pipe that collects water from a pool created by a small dam as shown in Figure 3. In addition, the City maintains a six-inch emergency intertie with the City of Cornelius, located at Heather Street at the City boundary.

2.1.2 JOINT WATER COMMISSION SUPPLY

The cities of Forest Grove and Hillsboro formed JWC in 1976 under Oregon Revised Statues 190 agreement. The current members of JWC include the cities of Forest Grove, Hillsboro, Beaverton and the Tualatin Valley Water District. JWC draws water from the Tualatin River during winter and has access to the 53,000 acre-feet Scoggins Reservoir during summer. JWC currently provides approximately 400 million gallons (MG) per year to the City, (approximately 36 percent of the City's total water supply needs), most of which is typically used during the peak water demand season from July through October. The City also uses the JWC water supply during the winter when the WTP requires maintenance, during high-turbidity events, or for other reasons.

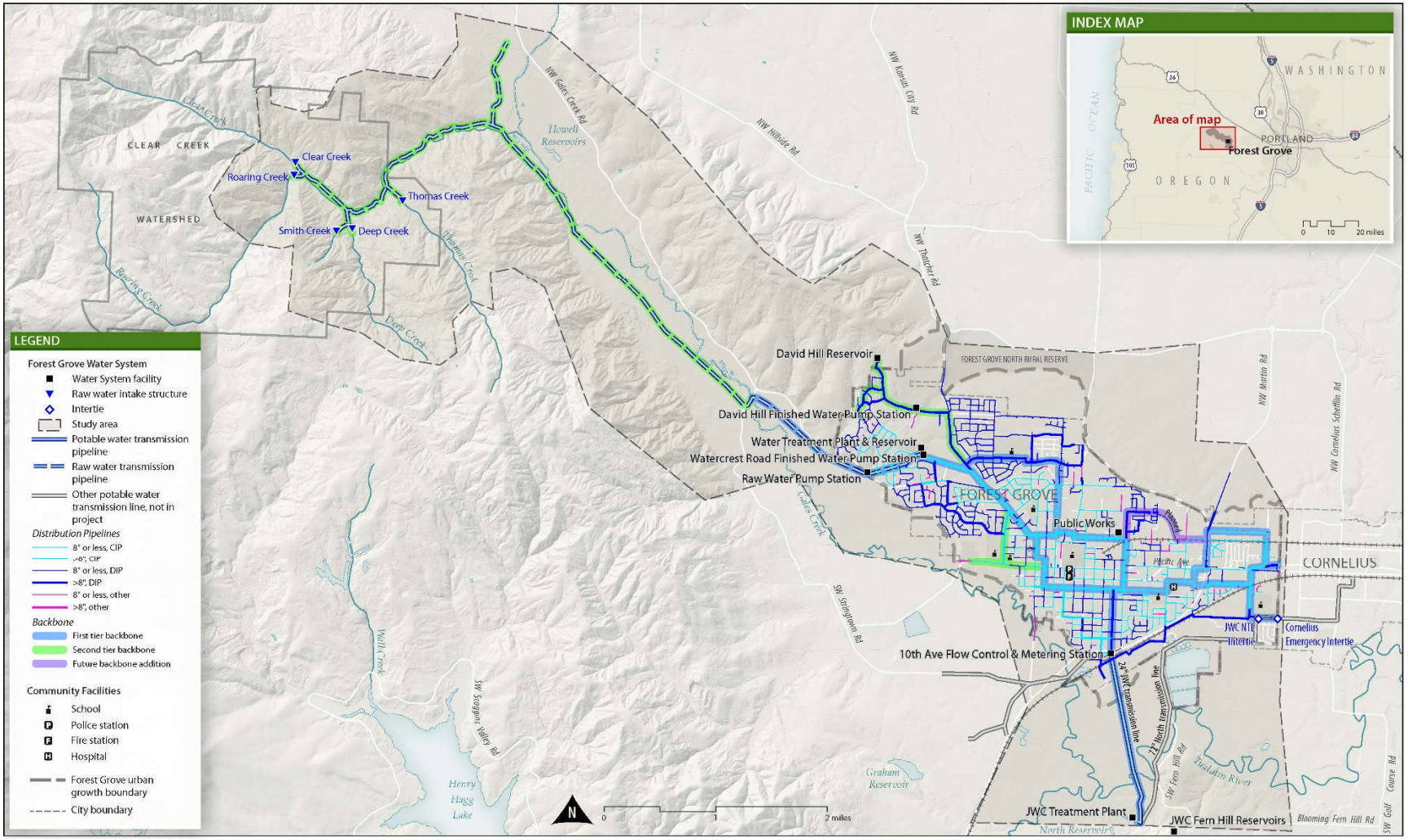
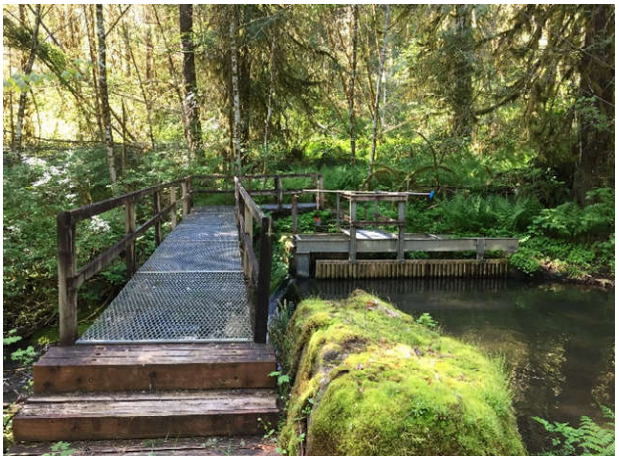


Figure 1: City of Forest Grove's Water System



River Intake – Deep Creek



River Intake – Roaring Creek

Figure 2: River Intake Facilities



Reservoir Pool and Dam



River Intake Perforated Pipe

Figure 3: River Intake Details - Typical

2.2 TRANSMISSION SYSTEM

2.2.1 RAW WATER TRANSMISSION MAIN

The raw water transmission system consists of two parts: (1) 8-inch cast iron transmission pipes from river intakes to the RWTM, and (2) a 16-inch RWTM that transports water from the Clear Creek watershed to the City's WTP.

The approximately 9.1-mile-long RWTM generally runs along Gales Creek and crosses the creek at the Stringtown Road Bridge. The bridge, located northwest of WTP is a two-lane reinforced concrete bridge owned and maintained by Washington County. At this location, the pipeline is suspended from the bridge as shown in Figure 4. In case of pipeline failure upstream of the Stringtown Road Bridge, there is provision to feed

raw water from Gales Creek to the RWTM through a blind flange (Figure 4), and from there to the WTP.



16-inch RWTP at Stringtown Road Bridge



RWTP Blind Flange for Emergency Intake

Figure 4: Stringtown Road Bridge Crossing

2.2.2 24-INCH FINISHED WATER TRANSMISSION LINE

Water from the Tualatin River is treated at the JWC WTP located on Spring Hill Road south of the City. The JWC WTP expansion to a total capacity of 85 MGD was completed in the summer of 2019.

Treated water from the JWC WTP is stored in two 20 MG Fern Hill Reservoirs (located Southeast of the JWC WTP). The City owns 5.3 MG of storage in the Fern Hill Reservoirs. Finished water from the reservoirs is transported through the 24-inch JWC finished water transmission line (JWC TL) which is approximately 1.6-mile-long concrete cylinder pipe (CCP) to the City's 10th Avenue Control Station. The 24-inch JWC TL is jointly owned by the cities of Forest Grove and Hillsboro but operated by JWC/Hillsboro staff. However, in a major earthquake City's staff may be needed to perform repairs to this pipeline if JWC/Hillsboro staff become unavailable.

2.3 DISTRIBUTION SYSTEM

The City's water distribution system consists of a total of 91.5 miles of pipelines. Pipelines within the distribution system are primarily cast iron and ductile iron pipes with a small amount of polyvinyl chloride (PVC), copper, and galvanized steel. Pipeline types for the distribution system are summarized in Table 1 and Figure 5.

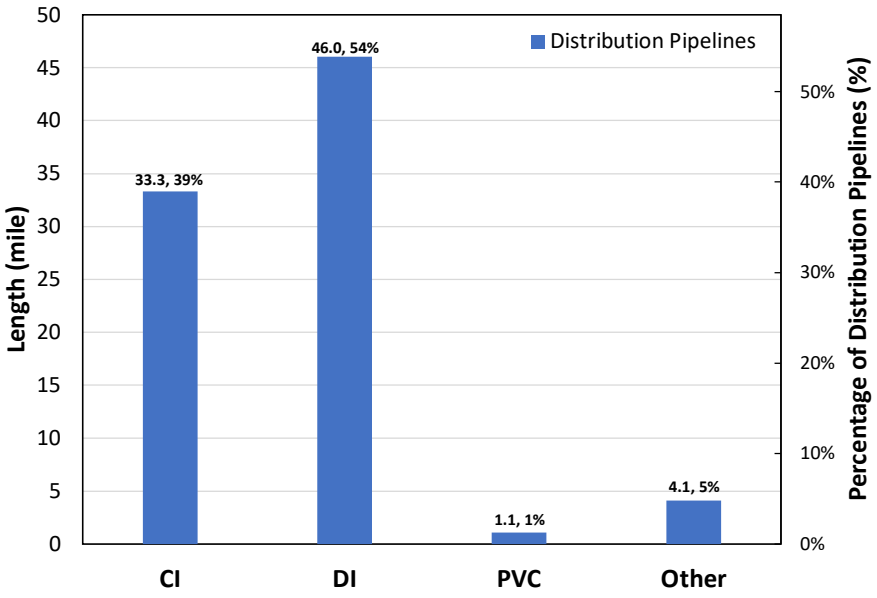
Pipeline lengths shown in Figure 5 are obtained from the GIS database provided by the City on June 5, 2018 (current at the time), and are somewhat different from the pipeline lengths shown in Table 1 and included in the Water System Master Plan (Murraysmith, 2020), which contains the most up-to-date data.

Table 1: City of Forest Grove Water System Pipeline Types and Lengths

Pipe Type	Distribution System (miles)[1]
Cast Iron (CI) Pipe	33.3
Ductile Iron (DI) Pipe	46.7
PVC Pipe	7.0
Other Pipe	4.6
Total[2]	91.5

Notes:

1. Pipeline lengths from the Water System Master Plan (Murraysmith, 2020).
2. Slight differences due to rounding.



Note:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018.

Figure 5: Percentage of Significant Pipeline Types in City's Distribution System

2.4 STORAGE SYSTEM

The City's storage system includes two reinforced concrete reservoirs. The larger of the two is a buried 5 MG reservoir located at WTP. The second is a 1 MG partially buried reservoir on David Hill Road just outside the city limits to the northwest (Plate 1). General information about the two reservoirs is summarized in Table 2, with a brief description provided below.

Table 2: Summary of City Reservoirs

Reservoir Name	Latitude	Longitude	Structure Type	Construction Date	Approx. Dimensions (feet)	Height (feet)	Capacity (MG)
David Hill	45.546	-123.146	Buried concrete	1985	76 x 96	18.5 to 22	1
WTP	45.535	-123.137	Buried concrete	1948	150 x 300	19	5

The WTP Reservoir was constructed in 1948. It is approximately 17 feet deep and has plan dimensions of approximately 150 feet long by 300 feet. The original reservoir did not include a roof over the reservoir basin. The design anticipated the construction of a roof in the future and included footings and vertical reinforcement for future columns to support a roof. A roof with dimensions nearly identical to the original 1948 design was constructed in 1980. Figure 6 shows photos of the reservoir prior to roof construction and in its current state.



Prior to Roof Construction Roof (1980)



Existing with Roof (2018)

Figure 6: 5 MG WTP Reservoir

The David Hill Reservoir was constructed in 1985 on a sloping hillside (Figure 7). The reservoir is approximately 76 by 96 feet rectangular in plan and is embedded between 13 and 16 feet in the ground. The City also owns 5.3 MG of storage in the Fern Hill Reservoirs owned and operated by JWC. As the Fern Hill Reservoirs are owned by all JWC partners, a seismic evaluation of the reservoirs was not performed.



Partially Buried David Hill Reservoir

David Hill Reservoir Roof

Figure 7: 1 MG David Hill Reservoir

2.5 WATER TREATMENT PLANT

The City's WTP is located at 501 Watercrest Road and includes multiple structures identified in Figure 8. A brief description of the most significant structures at the City's WTP and their function is summarized in Table 3.

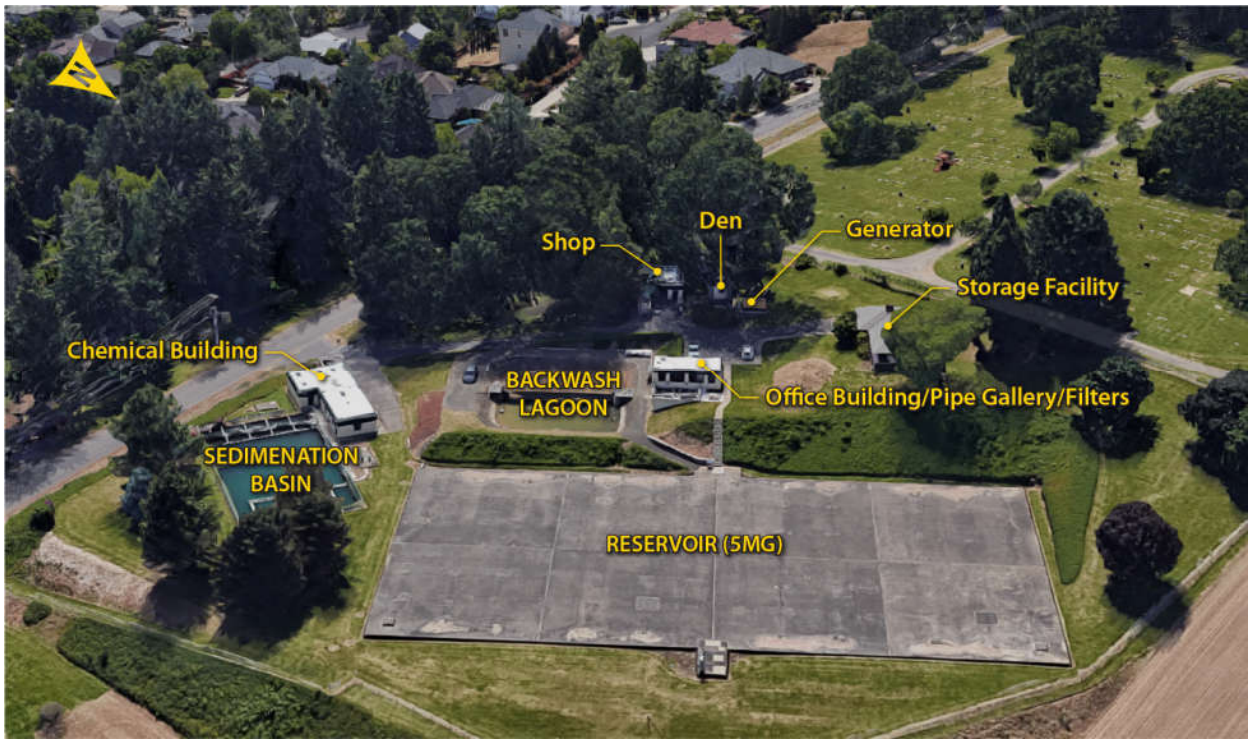


Figure 8: WTP and Reservoir Layout

Table 3: Summary of Structures within the WTP

Structure	Const. Date	Critical[1] (Y/N)	Stories	Approx. Size (feet)	Function
Chemical Building	1948	Yes	1	70 x 32	Part of chemical mixing and water treatment process
Office Building/ Pipe Gallery/ Filters	1948	Yes	Office on ground level Pipe Gallery and Filters on lower level	36 x 17.5	Office: Monitor/control of treatment system and testing. Pipe Gallery and Filters: Part of the water treatment process
Emergency Generator	Unknown	Yes	N/A	7 x 13	Supply electricity to operate WTP at full capacity for 32 hours. Comes online automatically if power outage > 3 seconds
Sedimentation Basin	1910	Yes	N/A	60 x 110	Part of water treatment process
Backwash Lagoon	1978 – 1979	Yes	N/A	65 x 70	Part of water treatment process
Shop	1980s	No	1	25 x 35	Waste disposal; misc.
Den	2002	No	1	15 x 25	Storage - tractor and misc. tools
Storage Facility	Prior to 1978	No	1	40 x 60	Storage of office items (e.g. historic drawings and photos)

Note:

1. A structure is defined as critical to the WTP if its failure prevents water treatment at the WTP.

2.6 OTHER FACILITIES AND STRUCTURES

Other facilities and structures within the City's water system include three pumping stations, the Public Works facility, and the 10th Avenue control station.

2.6.1 PUMPING STATIONS

City's pump stations include the raw water pump station, the Watercrest Road finished water pump station, and the David Hill finished water pump station (Figure 9). The location of each pump station is shown in Plate 1 and Plate 2. A brief description of each pump station and their function is summarized in Table 4.

Table 4: Summary of Pump Stations in City Water System

Name	Construction Date	Latitude	Longitude	Total Capacity (GPM)	Pump Station Function
Raw Water Pump Station	1979	45.531	-123.147	700[1]	Increases flows to the WTP when needed
Watercrest Road Finished Water Pump Station	1978	45.533	-123.137	280	Primary pump station feeding the David Hill Reservoir
David Hill Finished Water Pump Station	1985	45.540	-123.139	400	Backup to Watercrest Road Finished Water Pump Station

Note:

1. The gravity capacity of the raw water main is estimated by the City to be approximately 2,150 gallon per minute (GPM), or 3.1 million gallons per day (MGD). The raw water pump station can increase flows to the plant up to approximately 3.7 MG. The raw water pump station capacity is estimated to be the difference of increased flow and natural gravity flow.

2.6.2 10TH AVENUE CONTROL STATION

The 10th Avenue Control Station is located at 2540 10th Avenue. The building was constructed in the late 1970s. It is a single-story structure with concrete masonry unit (CMU) walls and a wood frame roof (Figure 9). The facility is connected to the 24-inch JWC TL and is typically used during the periods of peak demand from July through October or when the WTP shuts down for maintenance.



Raw Water Pump Station



Watercrest Finished Water Pump Station



David Hill Finished Water Pump Station



10th Avenue Control Station

Figure 9: Pumping Stations and 10th Avenue Control Station

2.6.3 PUBLIC WORKS FACILITY

The Public Works facility is located at 2251 23rd Avenue and includes an office building, an equipment storage building, a machine shop, a supply storage building, and a covered storage structure. These structures are summarized in Table 5 and shown in Figure 10.

Table 5: Summary of Structures at Public Works Facility

Public Works Structure	Construction Date	Stories	Approx. Dimensions (feet)	Function
Office Building and Machine Shop	1989	1	50 x 115	Office and servicing of City vehicles
Covered Storage Structure	Unknown	1	20 x 100	Vehicle storage
Supply Storage Building	Mid-1990s	1	40 x 125	Supplies and tools storage
Equipment Building	Unknown, possibly oldest at facility	2	60 x 105	Vehicle, supplies, and tools storage



Office Building and Machine Shop



Covered Storage Structure



Equipment Building



Supply Storage Building

Figure 10: Public Works Facility

3.0 PERFORMANCE OBJECTIVES

3.1 ORP GOALS FOR WATER

Recognizing the nature and extent of inherent vulnerabilities in an existing water system and the substantial cost of seismic mitigation, ORP recommends a phased approach for system improvement. The approach consists of the identification and strengthening of a backbone system that can provide water for critical needs such as fire suppression, first aid, emergency response, community use, and normal health and hygiene soon after the event while damage to the remainder (non-backbone) of the system is being addressed.

The backbone system should consist of key supply, treatment, transmission, distribution, and collection elements that can be upgraded, retrofitted, or rebuilt to withstand the M9 CSZ earthquake. ORP assumes an overall time frame of 50 years as a goal to implement system upgrades so that a reliable supply of water is available for critical needs following an earthquake.

The ORP identifies a broad set of performance goals or TSoR for seven water system response categories and recommended a timeline associated with meeting different levels of operability (20 percent to 30 percent, 50 percent to 60 percent and 80 percent to 90 percent) for each category. The seven categories are described below:

1. Availability of finished water at supply source such as water treatment plants and wells
2. An operational backbone system
3. Availability of water supply to critical facilities
4. Availability of water at key supply points for fire suppression
5. Availability of water at fire hydrants
6. Availability of water at community distribution centers
7. Restoration of the distribution system

The TSoR identified in ORP are shown in Figure 11.

CSZ M_w 9.0 Event Occurs ↓	Timeline					
ORP Category	**0 - 24 hours**	**1 - 3 days**	**3 - 7 days**	**1 - 2 weeks**	**2 weeks - 1 month**	**1 - 3 months**
Potable water available at supply source (WTP, wells, impoundment)	20 - 30% operational	50 - 60% operational		80 - 90% operational		
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational	80 - 90% operational					
Water supply to critical facilities available	50 - 60% operational	80 - 90% operational				
Water for fire suppression--at key supply points	80 - 90% operational					
Water for fire suppression--at fire hydrants			20 - 30% operational	50 - 60% operational	80 - 90% operational	
Water available at community distribution centers/points		50 - 60% operational	80 - 90% operational			
Distribution system operational		20 - 30% operational	50 - 60% operational	80 - 90% operational		

Figure 11: Oregon Resilience Plan Target States of Recovery

In summary, TSoR require a high degree of reliability from the backbone system. According to ORP, the backbone should be 80 to 90 percent operational within 24 hours following the earthquake. The goal for the availability of water for fire suppression at key supply points is also 80 to 90 percent within 24 hours. Goals for availability of finished water at the source and distribution system are 80 percent to 90 percent operational within one to two weeks. Water supply to critical facilities such as hospitals, first-aid facilities, command and control centers, and essential industries is expected to be 80 percent to 90 percent operational within 1 to 3 days. Supply to community distribution sites is expected to be operational within 3 to 7 days. It is expected that within a month the system should be close to its pre-earthquake condition.

3.2 BACKBONE SYSTEM

The project team, including InfraTerra[3] and City[4] staff participated in a workshop to identify critical components of the City's system that can serve as the backbone. Considerations for identifying system components to serve as backbone included:

- Providing access to water to a large portion of town
- Providing sufficient capacity for post-earthquake demands
- Providing water to critical facilities such as the Forest Grove Tuality Urgent 3 Care Facility and schools which can serve as shelters following an earthquake
- Including redundant elements, such that the goals of the backbone system can still be met should some elements fail

Backbone pipelines were prioritized such that water can be transported to (in descending priority) the City's central district, industrial district in the Northeast of town, and the loop up to David Hill Reservoir. Backbone pipelines with highest priority were identified as first-tier and the remaining as second-tier.

The backbone system for this project is shown in Plate 1 and Plate 2, and includes WTP, 9.1 miles of RWTM, 1.6 mile long 24-inch JWC TL, and 13.4 miles of distribution pipelines (0.7 miles of which are planned for the future, pending construction of new pipelines). It is possible that the backbone system identified as part of this project may change depending on future growth.

The 7.3 milesof the RWTM upstream of Stringtown Bridge, including the cast iron pipelines from the river diversion structures in the Clear Creek Watershed, and water distribution lines near the David Hill Reservoir, were classified as second-tier because of City's ability to alternatively feed raw water in an emergency from Gales Creek. The 1.8-mile-long section of RWTM between the Stringtown Bridge and WTP was classified as first-tier because this section is the only source of raw water supply to the WTP.

The JWC TL and the 10th Avenue Control Station have also been identified as a first-tier backbone as they provide redundant treated water supply should the RWTM downstream of Stringtown Bridge or the WTP fail; however, it depends on the seismic reliability of the Fern Hill reservoirs and the 24-inch JWC TL. Seismic assessment of the reservoirs and the JWC TL were outside the scope of this study. Information provided by the City suggests that the JWC WTP is seismically vulnerable and JWC water supply may not be guaranteed. A summary of backbone transmission pipelines is presented in Table 6.

[3] Ahmed Nisar, Mike Greenfield and Charles Scawthorn

[4] Rob Foster, Rich Blackmun, Derek Robbins, Rick Vanderkin, Brian Dixon, and Dave Nemeyer

Both the 1 MG David Hill and 5 MG WTP reservoirs were included as part of the backbone as they provide critical water storage for emergency needs following an earthquake. The 5 MG WTP reservoir was designated as part of the first-tier backbone, and the 1 MG David Hill reservoir was designated as part of the second-tier backbone.

Table 6: Transmission System Pipeline Types and Lengths

Pipe Type	First-Tier Backbone Raw Water Transmission Pipeline (miles)[1]	Second-Tier Backbone Raw Water Transmission Pipeline (miles) [1, 4]	First-Tier Backbone Finished water 24-inch JWC TL (miles) [1]
Concrete Cylinder Pipe[2]	1.8	6.0	1.6
Cast Iron Pipe[3]	-	1.2	-
Total	1.8	7.3	1.6

Notes:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.
2. Concrete Cylinder Pipe includes pipelines marked as CCP in City GIS files. Engineering drawings show details for both welded and non-welded pre-stressed steel cylinder pipe and coal tar enamel lined and wrapped steel pipe.
3. Cast Iron Pipe includes pipelines marked as CI and CI TYTON in City GIS files.
4. Minor difference in total length of second-tier backbone raw water transmission pipelines due to rounding.

Approximately 12.6 miles of distribution system pipelines that provide city-wide coverage are also identified as part of the backbone. Out of the 12.6 miles, 8.0 miles were designated as first-tier backbone. The first-tier backbone in the distribution system was selected to provide water delivery throughout the City and serve as emergency water supply points to key facilities such as Public Works, schools, police station, and fire station. In an emergency, these locations can serve as delivery points for finished water. Approximately 4.6 miles of distribution system pipelines were identified as second-tier and include pipelines from the David Hill reservoir to the first-tier backbone and pipelines in the western portion of the City.

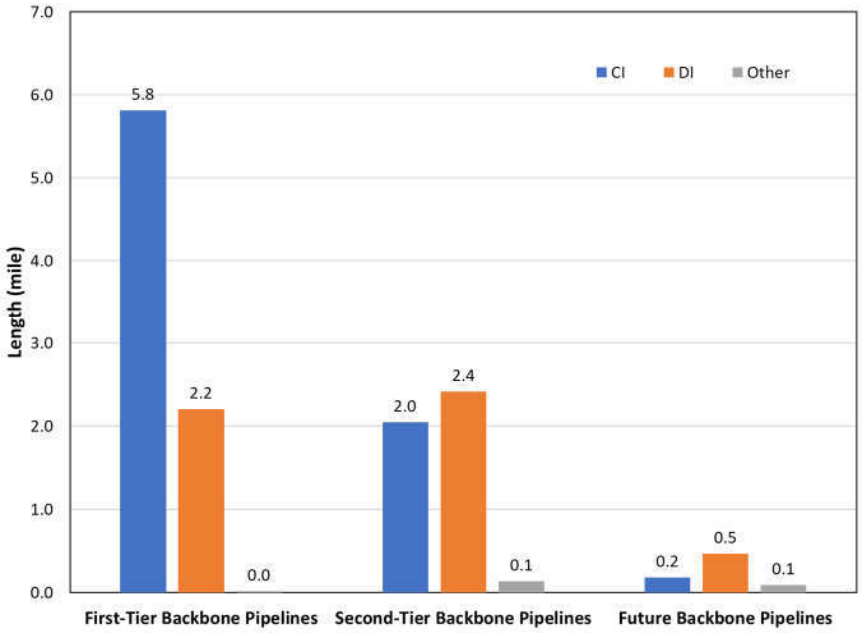
The backbone pipelines within the distribution system primarily include cast iron and ductile iron pipelines. An additional approximately 0.7 miles of pipelines are identified as future backbone, pending construction of new pipelines. The total lengths and pipe types of backbone pipelines within the distribution system are summarized in Table 7 and Figure 12 and shown in Plates 1 and 2.

Table 7: Distribution Backbone System Pipeline Types and Lengths[1]

Pipe Type	First-Tier Backbone System (miles) [2]	Second-Tier Backbone System (miles) [2]	Future Backbone System (miles)[6]
Cast Iron Pipe[2]	5.8	2.0	0.2
Ductile Iron Pipe[3]	2.2	2.4	0.5
Other Pipe[4]	<0.1	0.1	0.1
Total	8.0	4.6[5]	0.7[5]

Notes:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.
2. Cast Iron Pipe includes pipelines marked as CIP in City GIS files.
3. Ductile Iron Pipe includes pipelines marked as DIP City GIS files.
4. Other Pipelines include pipelines marked as C900 (PVC) and unspecified in City GIS files.
5. Minor difference in total length and sum of lengths of second-tier backbone and future backbone systems due to rounding.
6. Future backbones only include existing pipelines. Planned pipelines are not in the scope of this project.



Note: Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.

Figure 12: Pipeline Types in the Backbone Distribution System

3.3 POST-EARTHQUAKE FIRE DEMANDS

This section summarizes our assessment of post-earthquake fire demands for the City following an M9 earthquake. Although this study focuses on the M9 earthquake, fire demands from a Magnitude 6.8 (M6.8) local earthquake on the Gales Creek fault were also included for comparison. Additional details on post-earthquake fire demands are included in a technical memorandum (Appendix A).

3.3.1 FOREST GROVE FIRE & RESCUE RESOURCES

The City's fire protection services are provided by the Forest Grove Fire & Rescue (FGFR) that also provides rescue, fire response, emergency medical services, operations level hazardous materials response, fire prevention, and life-safety services (FGFR, 2016). FGFR operates two fire stations: Station 4, located in downtown and Station 7, located in Gales Creek.

Based on the information obtained from FGFR in 2018, the total pumping capacity of all apparatus in Station 4 is 9,623 gallon per minute (GPM) and 1,323 GPM in Station 7. The total for Station 4 includes 2,000 GPM for water tenders WT4 and WT7, which might be used for water shuttling rather than on-scene firefighting following an earthquake. There are numerous known alternative sources of water supply in the City, such as Gales Creek, the Tualatin River, and Council Creek. Based on the probable maximum relay distance of 2,000 feet for FGFR, about half of the City may be supplied from alternative water supplies (assuming relay capacity which, in some cases, are the same fire engines required at the fire ground).

3.3.2 ASSESSMENT OF IGNITIONS

Fire following an earthquake (FFE) is a highly non-linear process, which can only be modeled approximately (as discussed in Appendix A). In many cases the only clear result is the differentiation between a few small fires versus a major conflagration. Time is of the essence in successfully fighting FFE, because if unattended, small fires can develop into major conflagrations.

Estimation of FFE losses requires collection of data on building stock, ground conditions, water supply, fire services and estimation of earthquake shaking. The technical approach considers these factors in a stochastic framework to estimate (1) ignitions caused by the earthquake, (2) fire spread as a function of fuel (such as the building stock and contents), and (3) wind and firefighting activities (Scawthorn, 2018 and TCLEE, 2005).

The number of ignitions resulting from an M9 earthquake were estimated using the empirical relationships employed in HAZUS (SPA Risk, 2009). Due to relatively moderate levels of estimated ground shaking estimates in the City, the median number of ignitions from the M9 CSZ and M6.8 Gales Creek earthquakes were estimated to be 1 and 3, respectively, for an average time of day. A larger number of ignitions from the Gales Creek event are due to ground motions from this event due to its proximity to the study area. However, strong shaking from a Gales Creek earthquake has a much lower frequency of occurrence compared to that from the CSZ earthquake.

3.3.3 ASSESSMENT OF FIRE IMPACT

The City responds to about 35 fires per year (FGFR, 2016). Fires are typically reported via the Washington County Consolidated Communications Agency (WCCCA) dispatch center. In an earthquake the telephone system and dispatchers at WCCCA will likely be overloaded, and FGFR will probably learn of the fires by their own observations, citizen reports to Stations 4 and 7, and/or the engine companies during their post-earthquake survey. As a result, delay in response is likely. We estimate this delay will result in three incidents each impacting about 4,000 square foot of building floor upon first arrival of emergency services following an M6.8 earthquake the Gales Creek fault, and one incident with about 4,000 square foot for the M9 CSZ earthquake.

ORP recommends the fire hydrants to be 80 percent to 90 percent operational in two weeks to a month. Since most earthquake related fires occur within minutes to hours following an earthquake, fire water may not be available at fire hydrants immediately following the earthquake.

In the M9 CSZ earthquake, the Gales Creek Station 7 crew will most likely be required to remain in its vicinity and the City will have to rely on the resources of Station 4 and perhaps some state and federal wildland and private resources that cannot be quantified at present. Assuming the availability of current resources, it is likely that FGFR will be able to contain the fires resulting from the CSZ event.

The Gales Creek event is likely to result in one or two fires growing to large proportions if no outside resources are available. This is due as much to the limited resources of FGFR as to the damage and limitations of the City's water supply. The fires that grow to large proportions may each result in a loss of a city block, or several city blocks under adverse meteorological conditions. At this stage, fire defense would only be feasible at a fire break, such as a major street, and the fires would more than likely cease to further spread when they encounter an adequately large fire break (i.e., they exhaust available fuel).

Due to the regional nature of the CSZ event, limited resources may be available for firefighting, but for the local Gales Creek event resources will likely be available from surrounding areas. For planning purposes, water demands are estimated to be about 6,000 GPM for the Gales Creek event and about 2,000 GPM for the CSZ event.

3.4 PERFORMANCE GOALS FOR THE CITY OF FOREST GROVE

Using the guidance in ORP, key performance goals for City's water system components are recommended as shown in Figure 13.

CSZ M_w 9.0 Event Occurs	CSZ M_w 9.0 Event Occurs	Timeline					
ORP Category	**CFG Assets**	**0 - 24 hours**	**1 - 3 days**	**3 - 7 days**	**1 - 2 weeks**	**2 weeks - 1**	**1 - 3 months**
Potable water available at supply source (WTP, wells, impoundment)	1. RWTP from Stringtown Bridge to WTP 2. WTP facilities supporting treatment function 3. JWC transmission line	20 - 30% operational	50 - 60% operational		80 - 90% operational		
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational	1. First-tier backbone distribution pipelines 2. 5MG reservoir at WTP	80 - 90% operational					
Water supply to critical facilities available	1. All backbone pipelines 2. David Hill Reservoir	50 - 60% operational	80 - 90% operational				
Water for fire suppression--at key supply points	1. FGFR fire department capability to utlize alternative water sources to suppress fires 2. David Hill Reservoir continued operation 3. 5MG WTP Reservoir continued opration	80 - 90% operational					
Water for fire suppression--at fire hydrants	1. All pipelines required to supply hydrants (most of distribution system)			20 - 30% operational	50 - 60% operational	80 - 90% operational	
Water available at community distribution centers/points	1. Backbone distribution pipelines		50 - 60% operational	80 - 90% operational			
Distribution system operational	1. All transmission and distribution pipelines 2. All pump stations		20 - 30% operational	50 - 60% operational	80 - 90% operational		

Figure 13: City of Forest Grove Target States of Recovery

4.0 SEISMIC HAZARD MAPS

This Section describes the methodology used to develop earthquake hazard maps for the City's service area. These maps were developed for the M9 CSZ earthquake, and include the (1) liquefaction susceptibility map, (2) permanent ground deformation (PGD) map for liquefaction-induced lateral spread, (3) PGD map for liquefaction-induced settlement and (4) PGD map for seismically-triggered landslides.

Seismic hazard maps for the study area were based on incorporating both publicly available and project specific data. Assessment of seismic hazards included technical research and observations from recent earthquakes, including the March 11, 2011 M9.0 Tohoku, Japan Earthquake and the 2010-2011 Canterbury Earthquake Sequence[5] (CES; also referred to as Christchurch earthquakes) in New Zealand. These earthquakes produced widespread liquefaction and yielded a large amount of high-quality data. Case histories from these earthquakes resulted in revisions and refinements to liquefaction assessment procedures, which were implemented in this study. Data from the Tohoku earthquake is especially relevant due to its size and understanding of the influence of long duration shaking on liquefaction and liquefaction-induced PGD.

4.1 EARTHQUAKE SCENARIOS

The magnitude and frequency of the M9 CSZ earthquake contributes most significantly to the seismic hazard in the City. Due to the proximity of the City to the Gales Creek fault, a preliminary assessment of the potential impact of a large but rare earthquake on the Gales Creek fault on the City's water system was performed to provide a general understanding of the risk. Detailed assessment of a Gales Creek scenario was beyond the scope of this study.

4.1.1 CASCADIA EARTHQUAKE SCENARIO

Studies by United Stated Geological Survey (USGS) show that there have been numerous large-magnitude earthquakes along CSZ (USGS, 2012). Data on sea-bottom deposits formed by massive slope failures from strong earthquake shaking (turbidites) from as far back as 10,000 years show an average recurrence of about 500 to 530 years for great earthquakes (greater than M8) that have ruptured the entire or nearly the entire length of CSZ. The geologic record also shows an average recurrence interval of about 240 years for smaller, but still very large-magnitude, earthquakes

[5] The Canterbury Earthquake Sequence (CES) includes: M7.1 Darfield Earthquake on September 4, 2011; M6.2 Christchurch Earthquake on February 22, 2011; M6.0 Earthquake on June 13, 2011; and M5.8 and M5.9 earthquakes in December 2011

(M7 to M8) along the southern margin of the subduction zone. These records correlate well with the most recent M9 earthquake that occurred in January 1700, more than 300 years ago.

USGS study shows that there is a 7 to 12 percent probability of a great earthquake affecting the entire PNW in the next 50 years and as much as 21 to 42 percent for an earthquake along southern Oregon and northern California (Goldfinger et al., 2012; OSSPAC, 2013). The earthquake probabilities for the central and northern Oregon coast have recently been revised upwards to 16 to 22 percent (Goldfinger et al., 2016) in the next 50 years.

4.1.2 GALES CREEK EARTHQUAKE SCENARIO

Local crustal faults have formed in the Willamette Valley due to compression and tension in the earth's crust. The Gales Creek fault zone forms the boundary between the Oregon Coast Range and the Willamette Valley, and is the longest fault in the region. The fault zone extends nearly 75 km and strikes north-northwest parallel to Gales Creek.

This fault zone has been active at least since the Miocene epoch (23 to 5.3 million years ago) and fault activity is evident in the displacement of the Miocene Columbia River basalt to the northwest of the study area. No evidence of deformation in Quaternary (2.6 million ago to present) deposits has been described, but evidence of displacement may be concealed by the thick sedimentary deposits that have buried the fault. The USGS assigned a characteristic magnitude of M6.8 on the Gales Creek fault at a rupture depth of 9.0 km. The USGS assigns an average recurrence interval of about 64,000 years (Haller et al., 2002) for such an earthquake.

Recent trenching by the US Bureau of Reclamation show the fault to be active (Banse, 2018). Current ongoing work by Portland State University, USGS and Lawrence Livermore National Laboratory have found evidence for two surface rupturing earthquakes in the Holocene (12,000 years ago to present) period (Horst et al., 2018). Additional work and research into the frequency of past fault ruptures and the activity of the Gales Creek fault was still underway at the time of the writing of this report. Once a better understanding of the seismic activity of the Gales Creek fault is obtained, its impact on the City's water system should be assessed.

4.2 GROUND SHAKING HAZARD

The estimated ground shaking from the M9 earthquake on CSZ event is based on maps published by the Oregon Department of Geology and Mineral Industries (DOGAMI) in Open File Report O-13-06 (Madin and Burns, 2013). These maps were made part of ORP. Plate 3 through Plate 6 show ground surface peak ground acceleration (PGA) and

peak ground velocity (PGV) maps in the City's service area from the M9 earthquake on CSZ. For this earthquake, the median surface PGA and PGV ranges from about 0.20g to 0.27g (for PGA) and from 8 in/sec to 13 in/sec (for PGV), respectively. Most of the City urban growth boundaries have the PGA and PGV values close to the lower end of this range.

The USGS also simulated an M6.8 earthquake scenario with a rupture depth of 9.0 km on the Gales Creek fault zone. Ground surface PGA values from this earthquake ranges from about 0.42g to 0.61g in the study area (Plates 7 and 8). Although PGAs from the Gales Creek earthquake are significantly higher than the M9 CSZ earthquake, they have a much lower probability. The M9 CSZ earthquake is the primary hazard due to its higher probability of occurrence and region wide impact. The M9 CSZ earthquake will produce long duration shaking (lasting several minutes) that will result in significantly more damage than local, crustal faults of the same shaking amplitude.

Recently (when most of the work on this project had been completed), DOGAMI published updated surface ground shaking maps for the M9 CSZ earthquake in Open File Report O-18-02 (Bauer et al., 2018). These revisions resulted in significant changes from the 2013 maps. Near the WTP and David Hill Reservoirs, the 2018 PGA estimates are about 6 to 8 percent higher whereas in the southeast corner of the City boundary and in some areas along Gales Creek they are as much as 20 percent to 50 percent higher. The differences are largely due to the revised soil amplification factors (Federal Emergency Management Agency, 2015 and Appleby and others, unpublished) used in the 2018 study. These amplification factors are conservative and intended for use with the building design code. It is our opinion that the 2013 DOGAMI maps provide a more realistic estimates of ground shaking for the purposes of this study.

4.3 LIQUEFACTION HAZARD

Liquefaction is a process where strong ground shaking during an earthquake transforms granular soils from a solid state into a nearly fluid-like state, resulting in a reduced ability to support overlying soil layers and structures. Liquefaction occurs in loosely deposited saturated soils. When subjected to earthquake shaking that is strong enough or is repeated long enough, pore water pressure in saturated soils increase. When the excess pore water pressure exceeds the contact stresses between the soil particles, it results in a loss of soil structure and frictional resistance between particles causing the soil to lose its strength and flow like a liquid (hence the term, "liquefaction").

PGD from liquefaction is the primary cause of damage to water systems in large earthquakes. Recent examples of liquefaction-related ground deformation caused by earthquakes include large-scale damage produced during the 1989 Loma Prieta, California, 1994 Northridge, California, 1995 Kobe, Japan, 1999 Duzce, Turkey, 2001 Bhuj, India, and 2010/2011 CES in New Zealand. Liquefaction-induced lateral spread displacement can be on the order of several feet, especially near free faces, as observed in several past earthquakes (Figure 14).



Lateral spreading in Parking Lot – September 4, 2010 M7.1 Darfield Earthquake (Source: McSaveney)



Lateral spreading of Railroad Embankment in February 28, 2001 M6.8 Nisqually Earthquake in Capitol Lake, WA (Source: PEER)

Figure 14: Example Historic Occurrences of Lateral Spreading

Assessment of liquefaction hazard and its impact on water system components consists of two key steps; (1) assessment of liquefaction susceptibility and probability of its occurrence, and (2) estimation of ground deformation resulting from liquefaction.

Assessment of liquefaction susceptibility depends on the nature of subsurface soil, presence of ground water and the intensity of shaking. Liquefaction evaluations across a wide geographic area include a large amount of uncertainty because soil and groundwater conditions are not well-defined at that scale. Therefore, the potential for liquefaction is often described in probabilistic terms for regional scale analyses. The probabilities are typically grouped in generally descriptive categories such as low, moderate, high or other similar descriptors. However, such descriptions do not provide the necessary information for engineering assessment of structural or pipeline vulnerability, which require quantification in terms of the expected amount of PGD.

Sections below describe liquefaction susceptibility in the City's service area and estimation of ground deformation for use in pipeline vulnerability assessment.

4.3.1 LIQUEFACTION SUSCEPTIBILITY AND PROBABILITY OF LIQUEFACTION

Liquefaction susceptibility of soils in the City's service area was assessed based on recent updates to liquefaction assessment procedures (Boulanger and Idriss, 2014), additional details are provided in Appendix B. Although multiple other approaches are available, Boulanger and Idriss (2014) present the latest revisions and refinements to the procedure and include high-quality liquefaction case histories from recent earthquakes. The methodology also accounts for long-duration shaking from large subduction-zone earthquakes and the liquefaction potential of fine-grained soils such as silts.

For liquefaction assessment, a geologic map of the study area was first developed using existing data and observations from a geological reconnaissance of the study area on July 27 and 28, 2017. The existing data includes surficial geology mapping by DOGAMI (Smith and Roe, 2015), geotechnical borings from publicly available sources including the Oregon Department of Transportation (ODOT), DOGAMI, and the Oregon Water Resources Department and geotechnical reports provided by the City. The resulting geologic map for the study area is shown in Figure 15.

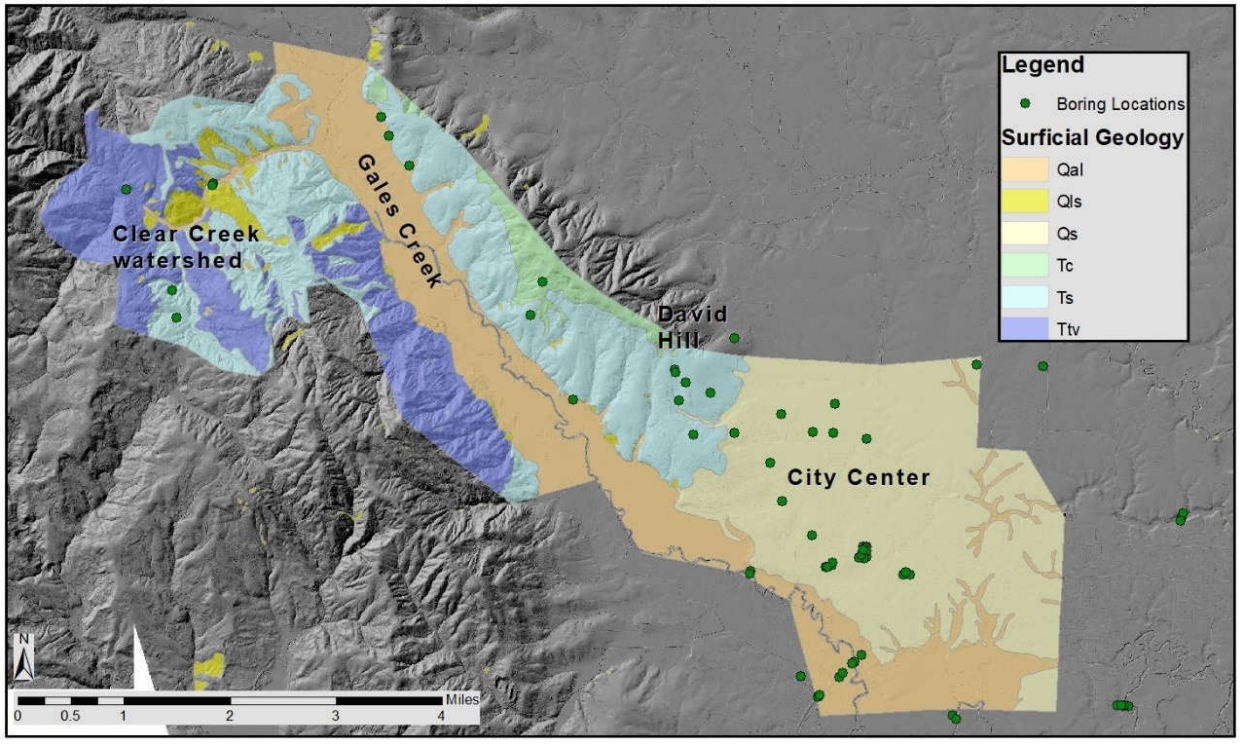


Figure 15: Study Area Geologic Map and Boring/Well Locations

Based on the data reviewed, only recent alluvium (Qal) and Willamette Silt (Qs) geologic units are found to be susceptible to liquefaction. These units are typically encountered along Gales Greek and within the City center, as shown in Figure 15. The

probability of liquefaction for each of the susceptible geologic units was calculated using the available subsurface data, the estimated depth to groundwater, and the estimates of the ground shaking. Rasters of liquefaction probability were developed in ESRI Geographic Information Systems (GIS). The severity of liquefaction was then estimated using classifications described by Maurer et al. (2014), which are provided in Table 8. The liquefaction severity classification for the project area is shown in Plate 9 and Plate 10. The plates show that liquefaction hazard in the study area ranges from very little to moderate. There were no areas found in the Forest Grove evaluation area that were classified as having severe liquefaction.

Table 8: Liquefaction Severity Classification

Classification	Probability of Liquefaction
Very little liquefaction	0 to 0.15
Marginal liquefaction	0.15 to 0.30
Moderate liquefaction	0.30 to 0.60
Severe liquefaction	0.60 to 1.0

4.3.2 LIQUEFACTION-INDUCED DEFORMATION

Liquefaction-induced PGD include lateral spreading and settlement. Lateral spreading is the permanent horizontal movement of a liquefiable soil deposit with non-liquefied crust in an area at or near a slope or a topographic feature. PGD from lateral spread can range from a few inches to several feet. It occurs predominantly in gradual slopes or at sites situated near riverbanks, shorelines, bulkheads, or wharves. Lateral spreading accounted for much of the damage to port facilities during the 1995 M6.9 earthquake in Kobe, Japan.

Liquefaction-induced ground surface settlement can occur through multiple mechanisms following liquefaction, including: (1) ejecta in the form of sand boils, (2) differential shearing due to lateral spreading, (3) lateral squeezing of very soft liquefied soil below foundations or embankments, and (4) dissipation of excess pore pressure from layers of liquefied soil as the soil densifies. Settlement due to pore pressure dissipation can occur over a period of days after an earthquake. Detailed analytical procedures (Boulanger and Idriss, 2014, Zhang el al., 2004; and Chu et al., 2016) with local subsurface and groundwater data were used to develop estimates for liquefaction-induced PGD for the study area. A discussion of the methodology used in this project to estimate liquefaction-induced deformations is provided in Appendix B.

Estimated liquefaction-induced deformations were incorporated in GIS to develop a liquefaction-induced lateral spread and settlement map for City service area as shown in Plates 11 through 14. The plates show that, except for locations along the RWTM

and the JWC pipelines, there is very little lateral spread hazard in the City. The liquefaction-induced settlement estimates are also relatively small (generally less than 3 inches). The PGD estimates developed for this study are median values. Since subsurface conditions are poorly defined at a regional scale, these PGD estimates include a significant amount of uncertainty.

For the study area, PGD estimates of about 2 inches or greater approximately correspond to areas classified as having marginal liquefaction severity. Areas where lateral spreading hazards become more likely are classified as having moderate liquefaction severity. The correlation between the probability of liquefaction and PGD estimates is difficult to accurately quantify because it depend on the soil behavior characteristics, depth of groundwater, soil density, and earthquake ground shaking intensity; all areas of significant uncertainty.

The PGD estimate in the study area are generally consistent with those shown in the 2013 DOGAMI Open-File Report O-13-16 (Madin and Burns, 2013). However, PGD estimates in the recent 2018 DOGAMI Open-File-Report O-18-02 (Bauer et al., 2018) show that at some locations these estimates are significantly larger in O-18-02 than those in O-13-06 and in our study. In some areas, these difference are as much as an order of magnitude. Likely reason for these difference is that O-18-02 used stronger ground shaking estimates through the use of conservative site amplification factors more applicable for code-based design. It is our opinion that liquefaction-induced PGD estimates in the 2013 DOGAMI study are more representative because they are based on local subsurface and groundwater data, whereas the O-18-02 used region-wide data and an assumed groundwater depth of 5.0 feet throughout.

4.4 EARTHQUAKE-TRIGGERED LANDSLIDES

Strong shaking from an M9 earthquake could also trigger landslides within the study area. Earthquake-triggered landslides are most likely to occur in areas of previous landslides activity. DOGAMI's Statewide Landslide Information Database for Oregon (SLIDO) project (Burns and Watzip, 2014) mapped historic and pre-historic landslides. Most existing mapped landslides within the study area are in the Clear Creek watershed or near David Hill as shown in Figure 16 and Figure 17. The figures show landslide deposits (identified as SLIDO deposits in the figure) and margins of the landslide (identified as SLIDO Scarp Flanks in the figure).

The DOGAMI landslide maps were used to supplement the earthquake-triggered landslide PGD maps developed for this study. Estimated strengths of surficial geologic units (Keefer 2000, Burns et al. 2013, and Dreyfus et al. 2013) were combined with available subsurface data to estimate the strength and thickness of the geologic materials. The factor of safety and yield acceleration were calculated using Scoops3D,

a 3-dimensional limit equilibrium slope stability program published by the USGS (Reid et al., 2015). The results were used to calibrate the estimated geologic strengths with observed conditions in order to refine and update the slope stability analyses. Earthquake-triggered landslide deformations were estimated on a regional basis using empirical correlations to rigid-block deformation analyses, which are conditioned on the yield acceleration, PGA, and earthquake magnitude. Additional details are provided in Appendix B.

The seismically-triggered landslide deformation maps developed for this project are shown in Plate 15 and Plate 16. The maps show that the overall landslide risk to the City's infrastructure from seismically-induced landslides is low, except in the Clear Creek watershed area and near the raw water pump station off Gales Creek Road.

In addition to the regional level landslide map (Plates 15 and 16), site-specific analysis of landslide hazard for the David Hill and WTP Reservoirs were performed and briefly described in Section 5.2 with details in Appendix C.

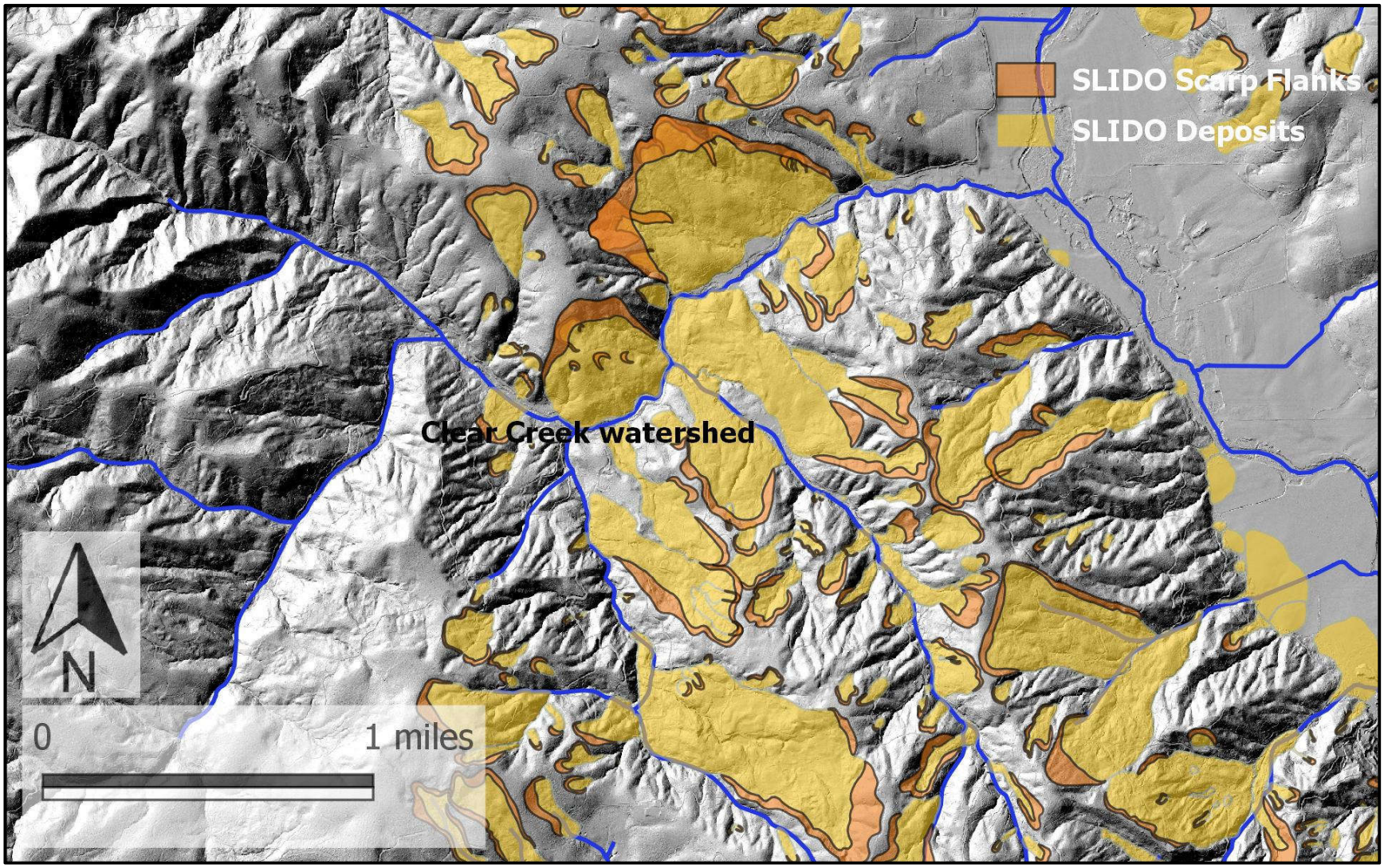


Figure 16: Mapped Landslides in SLIDO within the Clear Creek Watershed

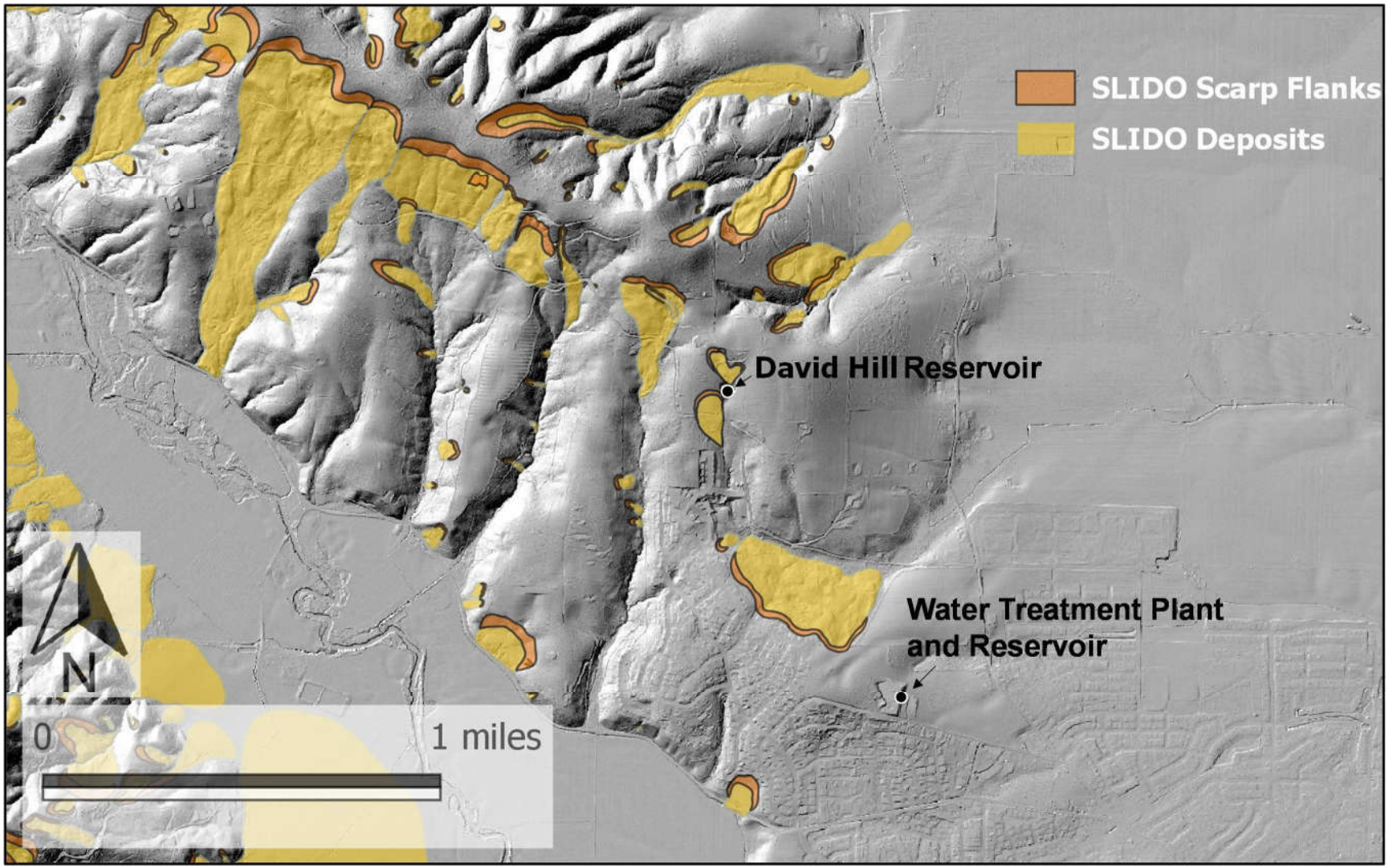


Figure 17: Mapped Landslides in SLIDO within David Hill

5.0 SEISMIC VULNERABILITY ASSESSMENT

This section describes seismic vulnerability assessment of City's water system assets including pipelines, reservoirs, WTP facilities, pump stations and public works facility.

5.1 PIPELINE SYSTEM

5.1.1 PIPELINE ASSESSMENT METHODOLOGY

The seismic response of buried pipelines depends on their complex interaction with the adjacent soil. It is a function of both the imposed ground deformation and the type of pipeline construction, especially joints. The imposed ground deformation include both permanent and transient components referred to as permanent ground deformation (PGD) and transient ground deformation (TGD), respectively. Ground failure from liquefaction, landslide or fault rupture results in PGD. Ground strains from seismic wave propagation causes TGD, which is a function of PGV. Distribution of PGV and PGD for the M9 earthquake in the City's service area is shown in Plates 5 through Plate 6 and Plate 9 through Plate 16, respectively.

Pipeline repairs are generally estimated using repair data from past earthquakes as a function of PGV and PGD expressed in the form of empirically derived pipeline fragility relationships. The empirical pipeline fragility relationships are developed using statistical analysis of pipe repair data from past earthquakes.

Some of the commonly available empirical fragility relationships for buried pipelines include the American Lifelines Alliance (ALA, 2001), Jeon and O'Rourke (2005); O'Rourke et al. (2014); and Bouziou and O'Rourke (2015). These fragility relationships are further discussed in Appendix D. Although close to 20 years old, the ALA relationships are still commonly used because of their simplicity. ALA uses mostly engineering judgment as a basis for repair estimates for different pipe types, and has a large amount of scatter in the data due to limited number of data points used to develop the relationships. For the purposes of this study the uncertainty range was taken as ±1 lognormal standard deviation (provided in ALA) around the median. In addition to uncertainty in repair estimates from pipeline fragility relationships, other sources of uncertainty include variability in ground motion and ground deformation due to unpredictability of earthquake shaking and its effects such as liquefaction and liquefaction-induced ground deformations.

Repair estimates typically include both leaks and breaks. A leak results from the loss of a pipeline's pressure boundary from joint pullout, a round or longitudinal crack, a local loss of pipe wall, or a local tear in the pipe wall (Shi, 2006), whereas a break is a complete disengagement of pipe with water flowing out to the atmosphere from the full cross-section of the pipe. Observations from past earthquakes suggest that leaks are more common and generally constitute 80 percent to 90 percent of total repairs (Ballantyne 2008).

For the City's pipeline network, the number of repairs was estimated using the PGD and PGV maps developed for this project. Based on sensitivity studies described in Appendix D, ALA's PGD-based pipeline fragility relationship was used for areas with estimated PGD values of greater than about 1 inch, and for all other areas, ALA's PGV-based pipeline fragility relationships (representing wave propagation effects) were used. For areas with PGD estimates greater than 1-inch, the largest deformation estimate resulting from lateral spreading, settlement, or landslides was used to estimate total number of pipeline repairs.

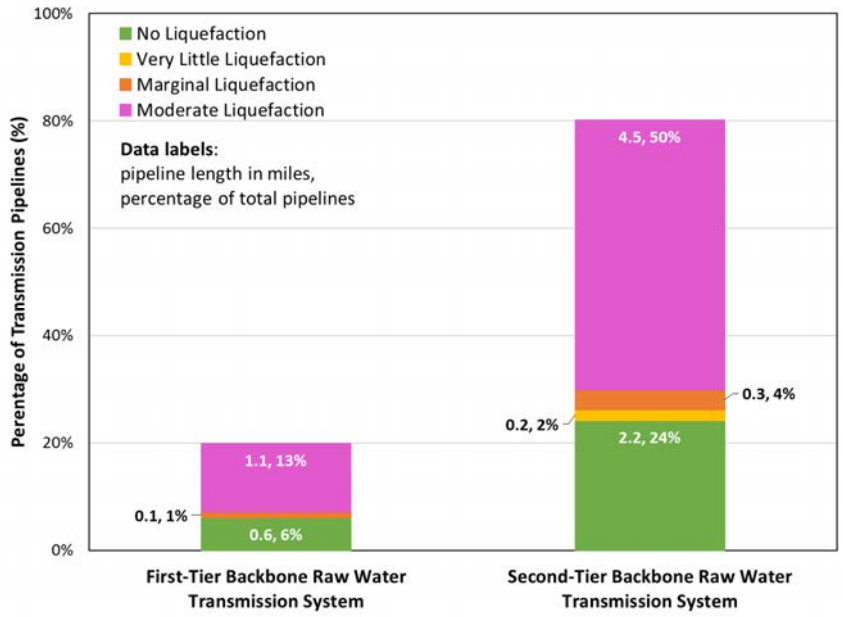
The total number of pipeline repairs were estimated based on the computed repair rates (repair/km) and the pipeline length in the City's water system using the pipeline lengths in the GIS database, dated June 5, 2018. Differences between the pipeline lengths presented in this report and in Murraysmith (2019) occur only in distribution pipelines and not in the backbone pipelines.

5.1.2 BACKBONE PIPELINES

The City's backbone water system includes 9.1 miles of RWTM, 1.6 miles of the 24-inch JWC TL and 13.4 miles of distribution system pipelines. The following sections summarize estimated repairs for different components of backbone pipelines.

5.1.2.1 Raw Water Transmission Main (Backbone)

The RWTM runs almost parallel to Gales Creek and is subjected to the significant liquefaction hazard along the creek. About 6.3 miles (70 percent) of the RWTM and feeder pipelines from river intakes to the RWTM are located within zones of very little and greater liquefaction hazard, and about 2.8 miles of transmission pipelines (30 percent) are in areas where liquefaction is unlikely to occur in the M9 earthquake. Figure 18 shows the length and percentage of raw water transmission pipeline located within different liquefaction susceptibility zones.



Note:

1. Minor differences in pipeline lengths in figure and in-text total due to rounding.

Figure 18: Raw Water Transmission System Pipelines in Different Liquefaction Susceptibility Zones

Using the approach described in Appendix D, median repair estimates for the first-tier (from Stringtown Road Bridge to WTP) and the second-tier (from river intakes to the Stringtown Road Bridge) backbone pipelines in an M9 earthquake are presented in Table 9 and Figure 19. The figure also shows the uncertainty in the estimated repairs by considering ±1 lognormal standard deviation around the median. As shown in the figure, the uncertainty in repair estimates is large. Variability in pipeline response to earthquake effects and the empirical nature of pipeline fragility relationships contributes to this uncertainty. For example, the first-tier backbone pipeline has a median estimate of 2 repairs but could be up to about 3 times larger, as shown in Figure 19. Similarly, a median of 11 repairs are estimated for the second-tier backbone pipeline, but could also be up to about 3 times larger.

Table 9: Median Estimate Raw Water Transmission System Pipelines Total Repairs

Pipeline Type	First-Tier Backbone		Second-Tier Backbone	
	Total Length[1] (miles)	Total Repairs	Total Length[1]	Total Repairs
Concrete Cylinder Pipe[2]	1.8	2	6.0	11
Cast Iron[3]	-	N/A	1.2	-
Total[4]	1.8	2	7.3	11

Note:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.
2. Concrete Cylinder Pipe includes pipelines marked as CCP in City GIS files
3. Cast Iron pipe includes pipelines marked as CI and CI TYTON in City GIS files
4. Minor differences in total length of pipelines due to rounding

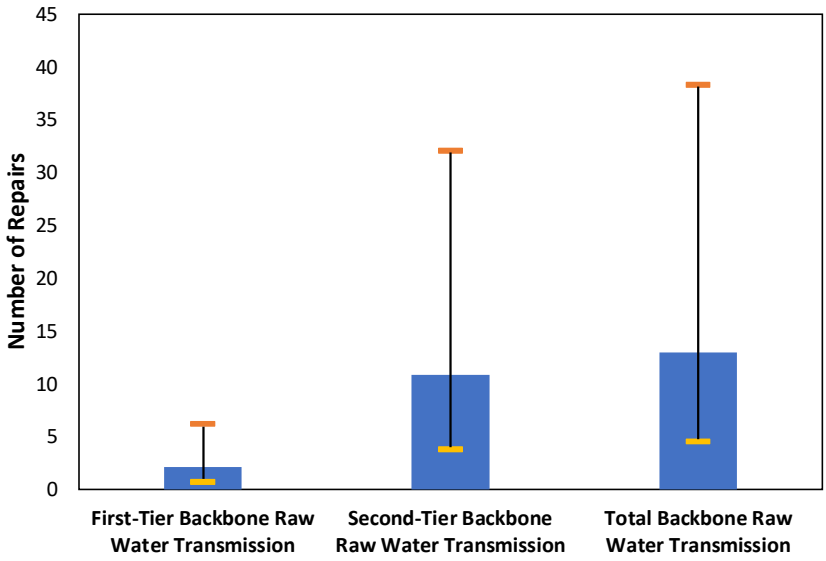
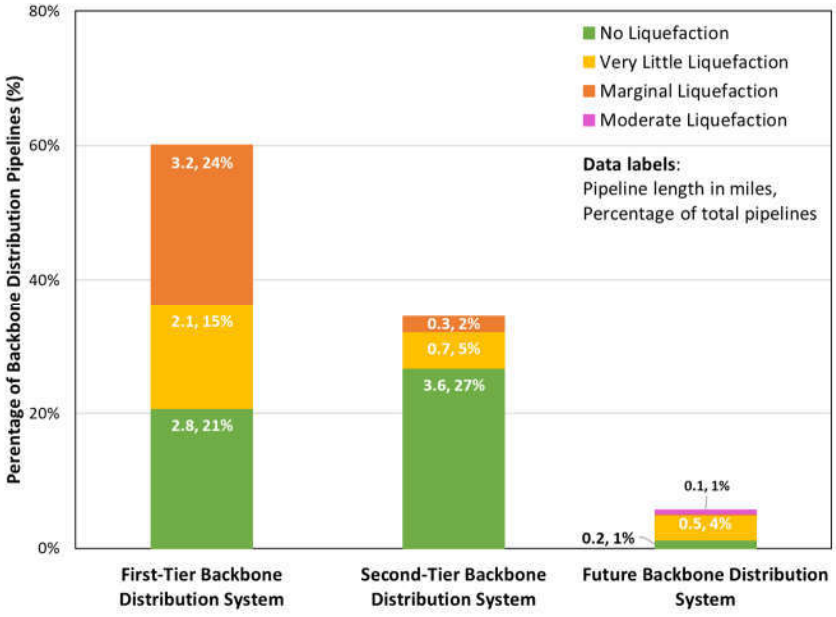


Figure 19: Raw Water Transmission System Pipelines Repair Median and Uncertainty Range

5.1.2.2 Backbone Distribution System

The City's backbone distribution pipelines are primarily cast iron and ductile iron. Cast iron pipelines are particularly vulnerable to damage in earthquakes. About half of all of the backbone distribution pipelines (6.9 miles) are located within zones of very little and greater liquefaction hazard. Of these, the majority (39 percent) consist of first-tier backbone pipelines, whereas the second-tier and future backbone pipelines constitute 8 percent and 5 percent, respectively, as shown in Figure 20.



Note:

1. Minor differences in pipeline lengths and percentages in figure and in-text totals due to rounding.

Figure 20: Backbone Distribution Pipelines in Different Liquefaction Susceptibility Zones

The lengths and estimated median repairs for the different classifications of backbone distribution pipelines are presented in Table 10. Figure 21 presents the median repair estimates and the uncertainty range around the median. As shown in the figure, we estimate a median of 29 repairs for the first-tier backbone pipelines, but could be up to about 3 times larger. Most of these repairs are in cast iron pipelines that have shown to be vulnerable to seismic damage in past earthquake. For the second-tier backbone pipelines, the median number of repairs is estimated to be 6 (could be up to about 3 times larger) and that for pipelines identified as future backbone the median repair estimate is 2 (could be up to about 3 times larger) repairs.

Table 10: Median Estimate Backbone Distribution Pipelines

Pipeline Type	First-Tier Backbone		Second-Tier Backbone		Future Backbone	
	Length (mi)[1]	Total Repairs[6]	Length (mi)[1]	Total Repairs[6]	Length (mi)[1]	Total Repairs[6]
Cast Iron[2]	5.8	25	2.0	5	0.2	< 1
Ductile Iron[3]	2.2	4	2.4	1	0.5	< 2
Other[4]	< 0.1	0	< 0.1	0	< 0.1	0
Total[5]	8.0	29	4.6	6	0.8	2

Note:

2. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which has since been updated.
3. Cast Iron pipe includes pipelines marked as CIP in City GIS files
4. Ductile Iron pipe includes pipelines marked as DIP City GIS files
5. Other pipelines include pipelines include unspecified pipelines in City GIS files.
6. Minor differences in total pipeline length due to rounding.

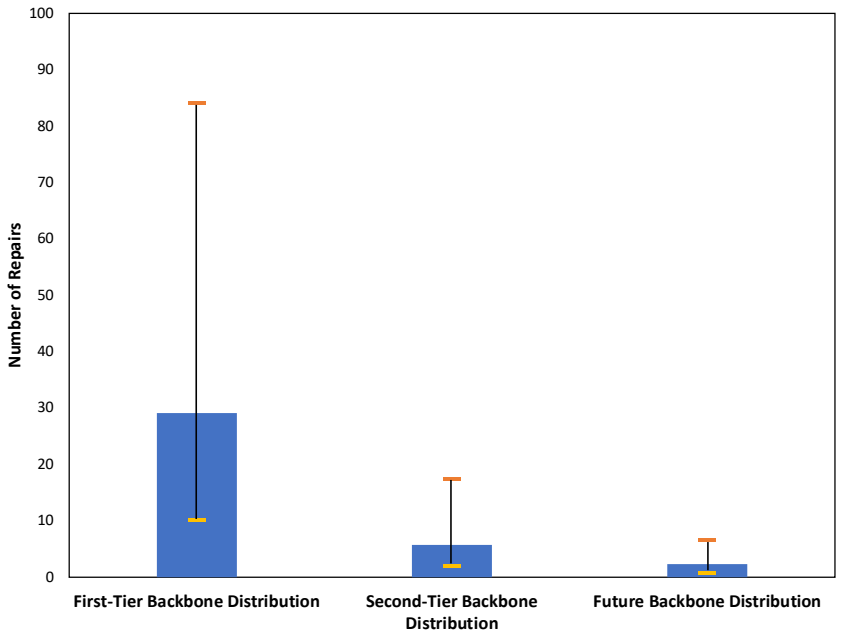


Figure 21: Backbone Distribution Pipelines Repairs Median and Uncertainty Range

5.1.2.3 24-inch JWC Finished Water Transmission Line (Backbone)

As shown in Plate 9 and Figure 22, most of the 24-inch CCP JWC TL (approximately 1.3 miles out of a total length of 1.6 miles) is subject to liquefaction hazard. Using the same approach as that for the raw water transmission system and backbone distribution system pipelines, a median value of 10 repairs (but could be up to about 3 times larger) are estimated. The median and uncertainty range for repairs is shown in Figure 23.

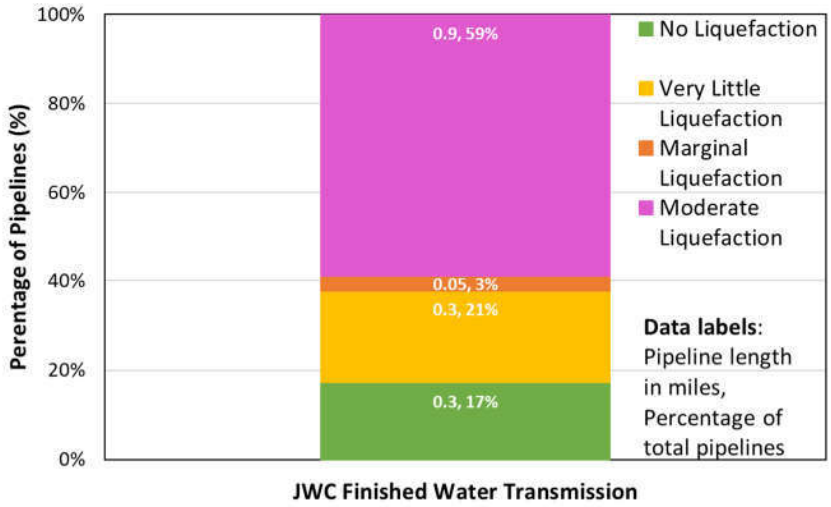


Figure 22: JWC Pipeline in Different Liquefaction Susceptibility Zones

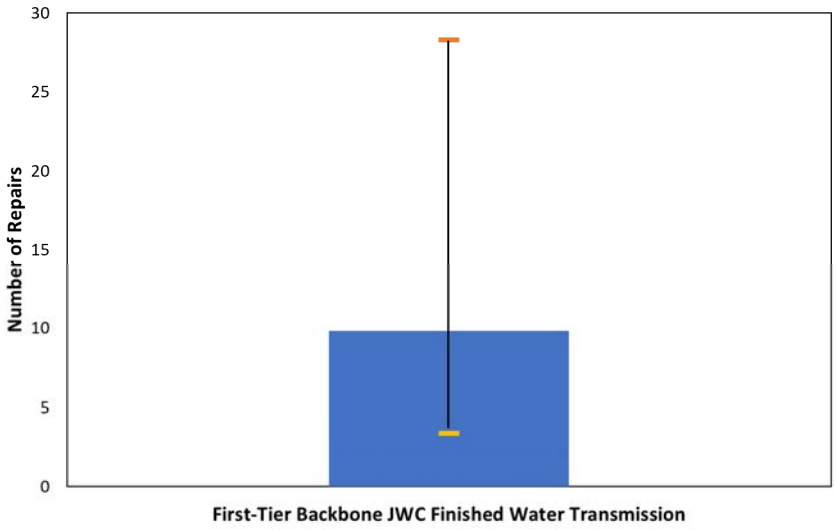
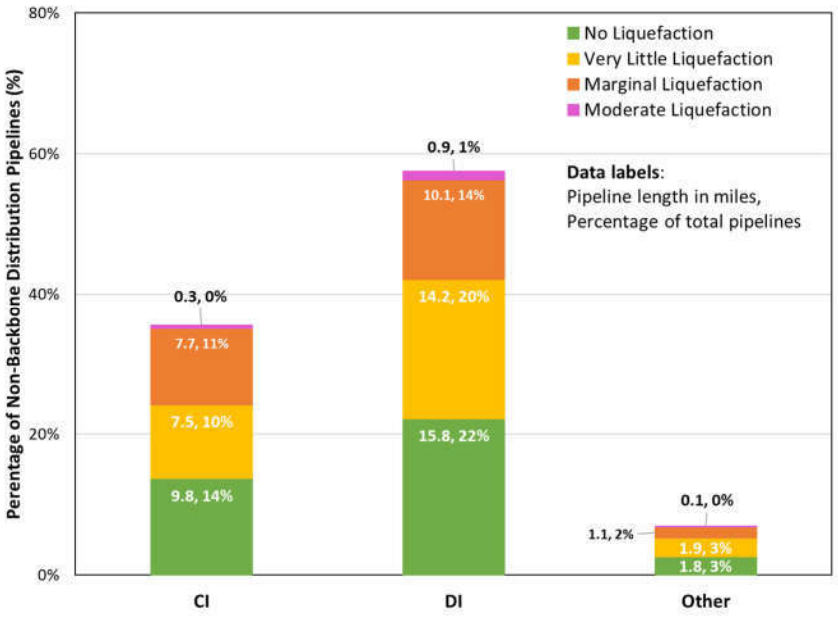


Figure 23: JWC Pipeline Repairs Median and Uncertainty Range

5.1.3 NON-BACKBONE DISTRIBUTION SYSTEM PIPELINES

Most of the non-backbone distribution system pipelines (43.7 miles[6], approximately 61 percent of total) are located within zones of marginal and greater liquefaction hazard (Plate 9). The total percentage of distribution pipelines in different liquefiable severity areas as a function of pipe type are presented in Figure 24.



Note:

1. Minor differences in pipeline lengths in figure and in-text total due to rounding.

Figure 24: Distribution System Pipelines in Different Liquefaction Susceptibility Zones

For the distribution system pipelines, a median of 213 repairs are estimated. Considering uncertainty, the total number of repairs could be up to about 3 times larger. The estimated repairs for different pipeline types are summarized in Table 11 and Figure 25. Approximately 50 percent of the estimated repairs are in cast iron pipes, 40 percent in ductile iron pipes and 10 percent in other pipeline types such as PVC, copper and steel. Most of the pipelines in the 'other' category are located in areas of very little and greater liquefaction hazard. The median repair estimate and ±1 standard deviation range is shown in Figure 25.

[6] Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.

Table 11: Median Estimate Non-Backbone Distribution Pipelines Repairs

Pipeline Type	Length (mi)[1]	Total Repairs
Cast iron[2]	25.3	106
Ductile iron[3]	40.9	86
Other[4]	4.9	22
Total[5]	71.1	213

Note:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.
2. Cast Iron pipe includes pipelines marked as CIP in City GIS files
3. Ductile Iron pipe includes pipelines marked as DIP City GIS files
4. Other include pipelines marked as C900, (PVC), PVC, COPPER (Copper), GALV/GALVINIZED (Galvanized Steel), GI (Galvanized Iron), POLY (Polyethylene), STEEL (Steel), and unspecified in City GIS Files
5. Minor difference in total repairs due to rounding.

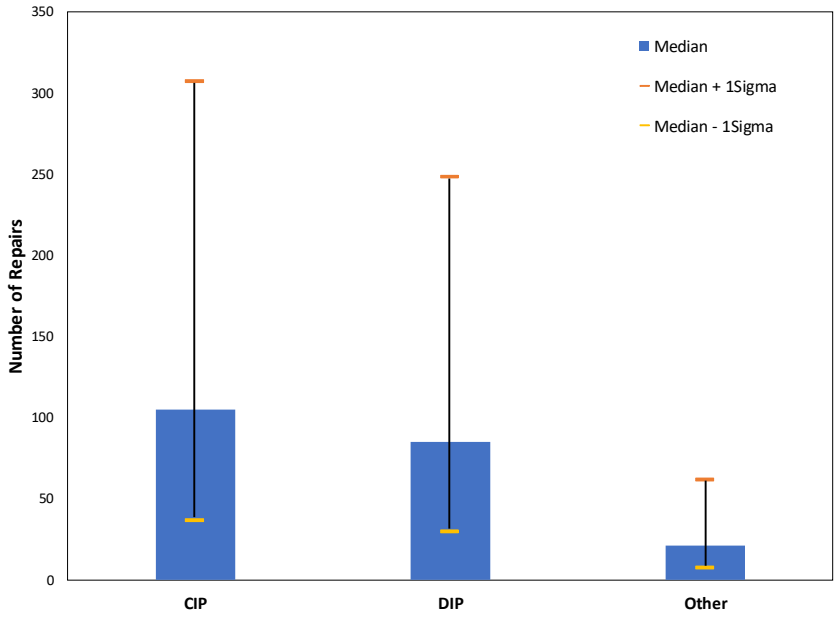


Figure 25: Distribution Pipelines Repairs Median ± 1-Standard Deviation

5.1.4 Summary and Discussion of Results

Table 12 provides a summary of the median estimated repair and an estimate of uncertainty for all pipelines within the City's pipeline network. This includes estimates for liquefaction-induced and landslide-triggered PGD and wave propagation-induced TGD. These estimates are based on conservative interpretation of pipeline construction especially the type of joints used. The largest concentration of repairs is estimated to be in areas susceptible to liquefaction with repairs occurring more frequently in areas with higher estimated PGD and older cast iron pipes.

Table 12: Summary of Best Estimate All Pipeline Repairs (M9 CSZ Earthquake)

Repair Estimates	Backbone System						Non-Backbone Distribution System
	Transmission			Distribution			
	First-Tier	Second-Tier	24-inch JWC TL	First - Tier	Second-Tier	Future	
Median Estimate	2	11	10	29	6	2	213
Upper Estimate[1]	6	32	28	84	17	7	616
Lower Estimate[2]	1	4	3	1	2	1	74

1 – Upper estimate represents median + 1 lognormal standard deviation
2 – Lower estimate represents median – 1 lognormal standard deviation

5.2 RESERVOIRS

Seismic assessments of the 5 MG reservoir at the WTP and 1 MG reservoir at David Hill were based on simplified structural calculations. The assessment was performed using existing data. No new geotechnical investigations were performed. The seismic hazard assessment considered ground shaking, liquefaction-induced lateral spreading and ground settlement, and slope stability. The structural assessment followed the guidelines of ACI 318-14 and ACI 350.3-06. A technical memorandum documenting these analyses is included in Appendix E and is summarized in the following sections.

5.2.1 WATER TREATMENT PLANT RESERVOIR

5.2.1.1 Seismic Hazards Assessment

The 5 MG WTP reservoir was constructed in 1948. The reservoir is underlain by stiff clean to sandy clays that are not susceptible to liquefaction.

The static slope stability analyses show that the factor of safety of the fill slope at the WTP is approximately 1.7 for average groundwater conditions and approaches 1.0 for high groundwater conditions. The analyses show that the fill slope below the WTP reservoir could deform about 2 inches (median estimate) in an M9 CSZ earthquake and about 0.5 inches (median estimate) in an M6.8 Gales Creek earthquake. These deformations would likely extend to the depth of the 20-inch supply line and possibly damage the line. Our analyses also show that the PGD at the reservoir is likely to be less than ½ inch in either the CSZ or the Gales Creek earthquake.

5.2.1.2 Structural Assessment

A structural assessment of the WTP reservoir was performed using the American Concrete Institute's standards ACI 318-14 and ACI 350.3-06. The reservoir is a critical element of the backbone and should maintain its storage capacity for emergency and firefighting needs. Due to its critical nature, an importance factor, *I*, of 1.25 was used for the assessment as described in the ACI standards.

Details of the structural/seismic assessment are provided in a separate technical memorandum included in Appendix E, with a summary presented in Table 13. The results show that the reservoir interior wall, exterior wall and roof support columns are vulnerable to damage in an M9 CSZ scenario earthquake.

Table 13: Summary of Structural Assessment for the WTP Reservoir

Structural Element	Failure Mode	Acceptable Performance?
Roof Support Columns	Compression	Yes
	Shear	Yes
	Bending	No
Central Wall	Compression	Yes
	Out-of-Plane Bending	No
Perimeter Walls	Compression	Yes
	Out-of-Plane Bending (Reservoir Empty)	No
	Out-of-Plane Bending (Reservoir Full)	No
Roof Slab	Sliding	Yes

5.2.2 David Hill Reservoir

The partially buried 1 MG David Hill Reservoir was constructed in 1985. The reservoir roof consists of an 8.5-inch thick reinforced concrete slab supported by 14-inch thick reinforced concrete walls and a 3-by-4 array of reinforced-concrete columns. The columns are 20-inch in diameter and are spaced 20-feet on centers. The floor slab is 6 inches thick and is underlain by a 12-inch thick layer of drain rock over the native material.

5.2.2.1 Seismic Hazards Assessment

The reservoir is underlain by stiff silt over siltstone, and is not susceptible to liquefaction. Landslides near David Hill have been previously mapped by DOGAMI and incorporated in DOGAMI's SLIDO project (Burns and Watzip, 2014). The SLIDO maps show locations of recent, historic, and pre-historic landslides near David Hill. Photographs provided by the City show evidence of small, relatively shallow landslides in the slope above the reservoir in the 1996 flood event (Figure 26). These landslides appear to be in man-made cuts and oversteepened slopes constructed as part of the road bench above the reservoir. Surficial raveling and severe erosion were observed along the road and at nearby slopes reservoir during the geology field reconnaissance performed by InfraTerra.

The static slope stability analyses for the fill slopes at the reservoir show that the reservoir has a factor of safety of about 1.4 for global stability with normal ground

water conditions and approaching 1.0 for high groundwater conditions, indicating that the slope may be unstable. A low factor of safety at high groundwater conditions is consistent with the observed historic landslides during prolonged periods of wet weather. The results of the seismic slope stability analyses show that the fill slope could deform about 4 inches in an M9 CSZ earthquake and about 1.5 inches in an M6.8 Gales Creek earthquake. Relative deformation between the reservoir and the fill slope could damage any piping that cross the deformation zone.



Landslide Behind Reservoir



Landslide Near Reservoir

Figure 26: David Hill Reservoir- Historic Landslides during 1996 Flood

5.2.2.2 Structural Assessment

A simplified and conservative analysis of the David Hill reservoir was performed. Similar to the WTP reservoir, an importance factor of 1.25 was used because the reservoir is a critical element of the backbone. Results of the seismic analysis for this reservoir are presented in a separate technical memorandum included in Appendix E, and summarized in Table 14. The results show that the bending moment capacity of the perimeter walls is exceeded for seismic loading.

Table 14: Critical Structural Elements and Failure Modes Considered in Assessment

Structural Element	Failure Mode	Acceptable Performance (Yes/No)
Roof Support Columns	Compression	Yes
	Shear	Yes
	Bending	Yes
Perimeter Walls	Compression	Yes
	In-Plane Shear	Yes
	Out-of-Plane Bending	No

The reservoir has good seismic detailing with the walls anchored into the roof and base slab with continuous reinforcement. The walls are also tied into the perpendicular walls with continuous reinforcement. It is likely that more refined calculations would show that the reservoir meets the imposed seismic demands. Therefore, additional more detailed seismic analysis is recommended.

5.2.3 Discussion and Summary of Results

The WTP and David Hill Reservoirs are critical elements of the City's backbone system and should maintain critical water storage for emergency use and fire fighting in a major seismic event.

Structural assessments of both reservoirs show seismic vulnerabilities. The WTP reservoir is the largest reservoir in the City's water system and was constructed in 1948. The reservoir roof support columns and walls (interior and exterior) are vulnerable to damage in an M9 CSZ event. It is recommended that the reservoir be seismically upgraded or replaced to the continued operation performance level to meet the City's performance objectives. A separate seismic evaluation performed by OBEC Consulting Engineers also recommended a retrofit of the columns and column footings of the reservoir (OBEC, 2018).

Simplified analysis of the David Hill reservoir walls shows potential vulnerability. However, the reservoir has good seismic detailing and more detailed analysis may show that the reservoir meets the performance requirement. Therefore, it is recommended that an additional detailed analysis be performed. If the results of such analysis still show vulnerability, then a seismic upgrade should be performed.

5.3 OTHER FACILITIES

Other facilities within the City's water system include pump stations, a treatment plant, 10th Avenue Control Station, and a Public Works facility. Site visits to these facilities were performed on March 19 and 20, 2018. Observations from the site visit are briefly discussed in the following sections, with photo documentation, structure descriptions, and details of seismic assessments included in Appendix F.

5.3.1 Water Treatment Plant

The WTP site is underlain by medium stiff clayey silt and stiff silt. These soils are not susceptible to liquefaction. A slope stability analysis of the adjacent slopes show that the WTP site is unlikely to be impacted by significant landslide deformation in an M9 CSZ event. Expected deformation of fill slope below the WTP reservoir is on the order of 2 inches in an M9 CSZ earthquake and about 0.5 inches in an M6.8 Gales Creek earthquake.

The TSoR for availability of finished water at supply source is 20 to 30 percent within 24 hours, 50 to 60 percent within 1 to 3 days and 80 to 90 percent in one to two weeks. Therefore, the WTP structures considered essential for water treatment were evaluated for the Immediate Occupancy performance level as defined in ASCE 41-17.

In ASCE 41-17, performance objectives are based on a pairing of seismic hazard levels and target structural and non-structural performance levels. ASCE 41-17 consists of six discrete structural performance levels as shown in Figure 27. Tables C2-4 of ASCE 41-17 illustrates the nature of the anticipated probable damage for these structural performance levels. For the "Immediate Occupancy (S-1)" performance level, considered for structures critical for treatment operations, there is expectation of limited structural damage, with the structural system retaining almost all of its pre-earthquake strength and stiffness. The risk of life-threatening injury as a result of structural damage is low, and although some minor structural repairs might be required, these repairs would generally not be required before re-occupancy.

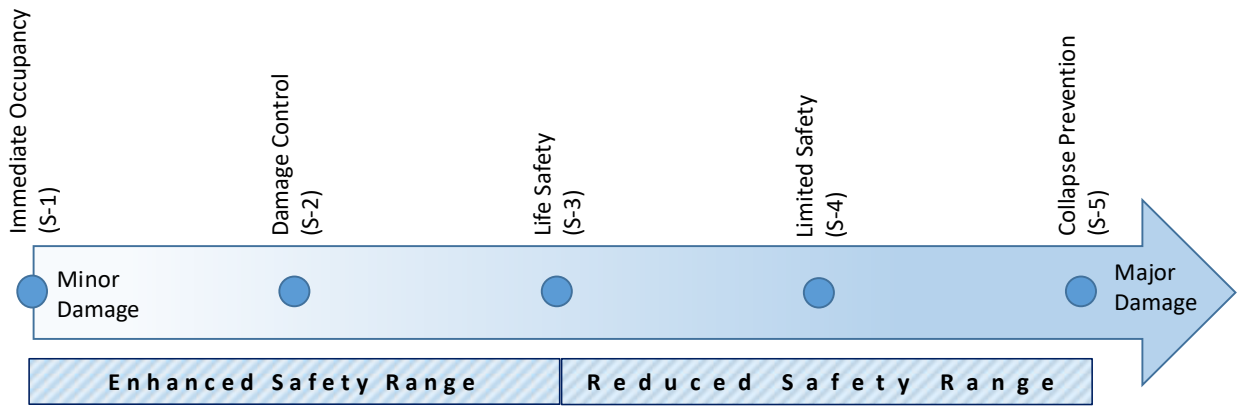


Figure 27: ASCE 41-17 Structural Performance Levels

The seismic assessment of these structures was based on a review of available drawings and simplified structural calculations for the estimated PGA of 0.21g for an M9 CSZ earthquake (Madin and Burns, 2013). The corresponding short period spectral acceleration S_s and one second spectral acceleration S_1 for the site are 0.52g, and 0.24g, respectively. Results of the structural/seismic assessments are summarized in Table 15 with details provided in Appendix F.

Our assessment shows that all of the structures at the WTP that are identified by the City as essential for operation of the plant meet the Immediate Occupancy performance criteria of ASCE 41-17. Some structural and non-structural damage is possible, but it is unlikely that such damage will result in significant disruption on plant operation in an M9 CSZ event.

Table 15: Structural Assessment Summary of WTP Structures

WTP Structure	Structure Type	Critical to WTP?[1] (Y/N)	Structural Vulnerabilities and Assessment (M9 CSZ Earthquake)
Chemical Building	Northeast section: reinforced concrete walls with wood-frame roof; Southwest section: concrete masonry unit walls and wood-frame roof	Yes	• The NE and SW sections have separate foundations - pounding damage is possible. • Multiple door/window openings, diagonal cracking likely near the corners of openings. However, the building's structural system has sufficient redundancy to limit the risk to life safety and structural collapse. • Sodium fluoride and sodium hypochlorite tanks are unanchored. Damage to tanks and piping is possible. • The building meets the base shear and roof anchorage checks of ASCE 41-17. • The building meets the Immediate Occupancy performance level of ASCE 41-17.

Office Building/Pipe Gallery/Filters	Reinforced Concrete	Yes	• Office Building
			  • Multiple window openings at the ground level.
			  • Cracking in reinforced concrete walls adjacent to window openings may occur.
			  • The building meets the Immediate Occupancy performance level of ASCE 41-17.
			• Pipe Gallery
			  • Partially buried reinforced concrete structure.
			  • Minor cracks in the walls may develop.
			  • Buried structures in competent soils (i.e. no liquefaction or ground failure) generally perform well in earthquakes, and; therefore, meets Immediate Occupancy performance level of ASCE 41-17.
			• Filters
			  • Partially buried reinforced concrete structure.
			  • Minor cracks in the walls may develop.
			  • Buried structures in competent soils (i.e. no liquefaction or ground failure) generally perform well in earthquakes, and; therefore, meets Immediate Occupancy performance level of ASCE 41-17.

WTP Structure	Structure Type	Critical to WTP?[1] (Y/N)	Structural Vulnerabilities and Assessment (M9 CSZ Earthquake)
Generator	N/A	Yes	• Generator is anchored to the base slab using four small-diameter anchor bolts along each longer dimension. These anchor bolts may fail in shear or yield in tension but are expected to prevent significant sliding or overturning. • Anchorage of the larger electrical cabinet could not be confirmed. It is recommended that anchorage should be checked. If the cabinet is not adequately anchored, limited sliding on the base slab is possible, overturning is less likely because of moderate levels of shaking and the width to height ratio approximately 2 to 3
Sedimentation Basin	Buried concrete structure	Yes	• Walls supported by counterforts, which are buttress-like elements that provide lateral strength and stability to the walls. • Minor cracking of the perimeter walls is possible, but is unlikely to significantly impact the structure's operation.
Backwash Lagoon	Buried concrete structure	Yes	• Moment-axial force interaction check for the divider wall completed. Capacity of the divider wall is not exceeded. • Minor cracking of the dividing wall between the two ponds is possible, but the operations of the Backwash Lagoon are not expected to be impacted.
Shop	Single-story concrete Masonry Unit (CMU) walls and a wood frame roof.	No	• Wide garage door opening and a door opening in the east wall • Cracking of the CMU walls, particularly in the corners at the door openings in the east wall is likely. • Building's structural system has sufficient redundancy that minimizes the risk to life safety risk and structural collapse. Immediate Occupancy performance level of ASCE 41-17 was not evaluated as the building is not critical to WTP operations. Additional assessment is needed to assess Immediate Occupancy performance level.
Den	Non-engineered single-story wood frame	No	• No significant vulnerability.
Storage Facility	Single-story wood frame	No	• Little information available. • More detailed inspection needed if structural assessment is necessary.

Note:

1. A structure is defined as critical to the WTP if its failure prevents the treatment of water at the WTP

5.3.2 PUMP STATIONS

The City's pump stations include the David Hill finished water pump station, the Watercrest Road finished water pump station, and the raw water pump station on the RWTM. The regional liquefaction hazard study shows that liquefaction and liquefaction-induced ground deformations are not anticipated at the pump stations. No historic landslides have been mapped near the pump station locations and our regional earthquake-triggered landslide analyses do not indicate a significant landslide hazard.

A structural assessment was performed to identify structural vulnerabilities of the pump stations and is summarized in Table 16. Detailed observations and photographs are attached in Appendix F.

Table 16: Pump Station Structural Assessment Summary

WTP Structure	Structure Type	Critical to WTP?[1] (Y/N)	Structural Vulnerabilities (M9 CSZ Earthquake)
David Hill Finished Water Pump Station	Single-story structure with concrete masonry unit walls and vertical (#5 bars, spaced 48 inches) and horizontal (#5 bars, unknown spacing) reinforcement	No	• Cracking near the corners at the door opening in the east wall is possible in anM9 CSZ event. • The building meets base shear and roof anchorage checks of ASCE 41-17 • The building meets Immediate Occupancy performance level of ASCE 41-17.
Watercrest Road Finished Water Pump Station	Buried reinforced concrete	No	• None significant
Raw water Pump Station	Buried reinforced concrete	No	• None significant

Note:

1. A structure is defined as critical to the WTP if its failure prevents the treatment of water at the WTP

5.3.3 PUBLIC WORKS FACILITY

The City's Public Works Facility includes the Office Building and Machine Shop, Covered Storage Structure, Supply Storage Building, and Equipment Building.

The Public Works Facility is underlain by silty soils (Qs), which may be susceptible to liquefaction. Based on our regional study, we estimate about 2 inches of liquefaction-induced ground settlement in an M9 CSZ earthquake. Because the site is relatively flat, earthquake-induced landslides are not a hazard. A structural assessment was performed to identify structural vulnerabilities, which are summarized in Table 17.

Detailed observations and photographs are attached in Appendix F. Structural drawings were not available and thus, detailed structural analyses could not be performed.

Table 17: Public Works Facility Structural Assessment Summary

Public Works Structure	Structure Type	Structural Vulnerabilities (M9 CSZ Earthquake)
Office Building and Machine Shop	Single-story structure with CMU walls; the material used for the framing of the pitched roof could not be established during site visit	• Multiple openings in walls, including three large garage door openings in the Machine Shop part of the building. Cracking of the CMU walls is possible, particularly near the openings in the walls. • Oil storage containers inside the Machine Shop observed to be unbraced and may topple. • Due to difference in height, structural damage is possible at the interface between the Office Building and the machine Shop section of the building. • The building structural system has sufficient redundancy to limit collapse and life safety risk. • Recommended more detailed structural assessment to evaluate the Immediate Occupancy performance level of ASCE 41-17.
Covered Storage Structure	Single-story simple wood frame	• No lateral bracing along the open front side. • Could be at risk of significant lateral deformations and structural damage, leading to potential collapse.
Supply Storage Building	Single-level light steel frame	• Large garage door openings in one of the walls. • Multiple shelves and their content present a falling hazard. • Not expected to sustain significant structural damage. • Expected to meet Life Safety and Immediate Occupancy performance levels of ASCE 41-17.
Equipment Building	Two-story structure with CMU walls; wood framing material could not be established during the site visit	• Multiple large openings in the CMU walls, including large garage doors, doors, and windows. • Cracking of the CMU walls, particularly near the corners of the door openings, is likely. • Recommended more detailed structural assessment to evaluate the Life Safety and Immediate Occupancy performance levels.

5.3.4 10TH AVENUE CONTROL STATION

The 10th Avenue Control Station is underlain by recent alluvium (Qal), which may be susceptible to liquefaction. Based on the regional study, we estimate up to 2 inches of ground settlement in an M9 CSZ event. Because it is located on relatively flat ground, earthquake-induced landslides are not a hazard at this site.

The building is a single-story structure with concrete masonry unit (CMU) walls and a wood frame roof. Diagonal cracking in the north CMU wall was observed near the

large diameter pipe penetration in the wall. While cracking of the CMU walls, particularly near the locations of existing cracks is possible in a major earthquake, the building structural system has sufficient redundancy to limit collapse and life safety risk. However, given the importance of this facility as it connects the JWC TL to the City's distribution system, it is recommended a detailed evaluation of liquefaction hazard and structural response be performed to meet ASCE41-17 Immediate Occupancy performance level. In addition to the structural evaluation, the facility has rigid pipe penetrations in the floor slab and the exterior wall. Due to the potential risk of liquefaction, it is recommended that flexibility be provided to the rigid pipe to wall and pipe to slab penetrations.

5.3.5 STRINGTOWN ROAD BRIDGE CROSSING

The Stringtown Road Bridge is owned and maintained by Washington County. The bridge is a two-lane reinforced concrete bridge that crosses Gales Creek just outside of the northwest corner of the City's urban growth boundary. The bridge deck is supported on two reinforced concrete piers on either side of Gales Creek. Two pipelines (one of which is the 16-inch backbone RWTP) are suspended from the bridge using 24-inch steel rods.

The bridge piers are likely founded on rock below alluvial soils (Qal). Recent alluvium is susceptible to liquefaction and due to the proximity of the bridge abutment to the bank of Gales Creek, up to 3 feet of liquefaction-induced lateral spreading may occur in an M9 CSZ earthquake.

Due to the length of the span and the steel rods supporting the pipelines, limited force and deformation transfer is expected to occur between the bridge and the pipelines. Potential cracking of the reinforced concrete bridge in an M9 CSZ earthquake is not expected to directly affect the pipelines. ODOT (1995) performed a seismic vulnerability study to prioritize local agency bridges for seismic retrofit. The study assigned Group 2B to the Stringtown Road Bridge owned by Washington County. According to the study, Group 2B includes bridges that have three substructure deficiencies consisting of (1) inadequate splices of main longitudinal column reinforcement to the footing dowels, (2) inadequate confinement of main longitudinal reinforcement in concrete columns, and (3) inadequate footing anchorage or absence of reinforcement in the top of footing. In addition to these identified deficiencies the bridge will likely experience liquefaction-induced permanent ground deformation. It is recommended that the City considers securing its pipeline either through retrofit of the bridge or separating the pipeline from the bridge and designing the pipeline to withstand liquefaction and ground shaking.

6.0 POST-EARTHQUAKE REPAIR

Restoration of the water system following a major earthquake requires consideration of system operation and repairs. Operational response requires that the damaged portions of the system are rapidly identified and isolated to minimize the loss of water. Estimation of restoration time is based on availability of equipment, materials, and manpower resources to complete repairs and bring the system to its pre-earthquake condition.

6.1 CITY REPAIR RESOURCES

6.1.1 EQUIPMENT

The City owns a range of equipment needed for pipeline repair and replacement including one backhoe, one excavator, two hydro-excavators, and one water service pickup truck to support the hydro-excavator. The hydro-excavator is operational without the water service pickup truck but would require more preparation time. Thirteen of the City staff are trained to operate the hydro-excavators. Additionally, the electric power group has an additional backhoe and mini-excavator that may be available but could also be needed for repairs to the electrical system.

All of the City's construction equipment and vehicles are located at the Public Works yard.

6.1.2 STOCKPILE MATERIAL

Construction materials and spare parts are stockpiled at the City's Public Works yard with other City infrastructure. As shown in the liquefaction hazard map (Plate 14), the Public Works facility may experience some liquefaction-induced settlement of up to 2 inches.

Stockpile materials for pipelines primarily include smaller diameter pipe that could be used for a limited number of repairs in the distribution system but not in the larger pipes of the backbone. At present, the City does not have sufficient stockpile to repair all of the estimated pipeline damage.

A breakdown of repair estimates distribution of sizes for the backbone and non-backbone distribution system is shown in Table 18 and Table 19. Figure 28 shows the median estimate of repairs in the backbone (transmission and distribution) and distribution system pipelines. The number of repairs shown in the tables is a reasonable estimation of material needed for post-earthquake pipeline repairs. Approximately 10 percent of these repairs can be considered to be breaks, and the

remaining as leaks. The raw water transmission system is not shown in these figures since 99 percent of the repairs are estimated to be on the 16-inch CCP. The JWC pipeline consists only of the 24-inch CCP and therefore is also not shown.

The current stockpile of clamps and sleeves are for smaller pipe sizes. Additional stockpile material for larger pipe sizes will be required to meet the recovery goals of the ORP. However, there are challenges associated with stockpiling significant quantities of repair materials due to space restrictions and damage/deformation that can occur over time as the material is not frequently used.

Table 18: Total Median Repairs in Backbone Distribution System

Material	6-inch	8-inch	10-inch	12-inch	16-inch	20-inch	24-inch
CIP	1	11	7	8	1	2	--
DIP	--	1	5	1	--	--	1

Note:

1. Repairs rounded to the nearest whole number, may differ slightly from values in previous tables

Table 19: Total Median Repairs in Distribution System

Material	2-inch	4-in	6-inch	8-inch	10-inch	12-inch
CIP	3	1	68	32	2	1
DIP	--	1	20	52	8	5

Note:

1. Repairs rounded to the nearest whole number, may differ slightly from values in previous tables

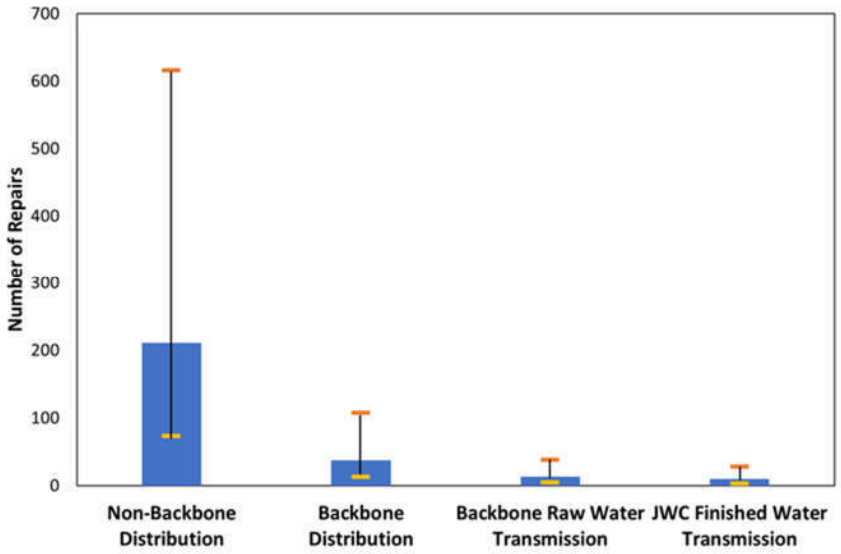


Figure 28: Pipeline Repair Estimates

6.2 PIPELINE REPAIR

The number of post-earthquake repairs that can be completed in a single day is dependent upon availability of crew, equipment, material and access. The most time-consuming elements of a repair are excavation, hauling, and backfill, which are all typically performed by a single repair crew, which may include a backhoe operator, a dump truck operator, a mechanic, and two utility workers. To rapidly respond to a significant number of pipeline repairs, post-earthquake pipeline repair protocols need to be established. This could include separating the hauling and backfilling operations from the excavation and repair operations. The crew responsible for excavation and repair could side cast the excavated material, perform the repair, and move on to the next repair, while a separate crew performs the haul and backfill operations.

The City has the capability of repairing small diameter pipelines (generally less than 12 inches in size). It is estimated that the time required to repair a single leak is at least 4 hours for smaller pipes (8 to 10 inches or less) and could take at least a day for larger pipes. For minor repairs such as leaks, it is estimated that on average, a single crew can make approximately three repairs to smaller pipes and one repair to a large pipe in a single 12-hour shift (assuming material availability). These estimates assume an expedited repair procedure with temporary side-casting and proper backfilling at a later time.

Repair of larger pipes and significant breaks can take 12 to 24 hours if material is readily available. If material needs to be special ordered and shipped to the City it could take longer, especially if transportation routes are impacted. Material availability could also be a problem in an M9 CSZ earthquake due to its region-wide impact.

Assuming three repairs per day for 12 inches or smaller pipelines and one repair per day for larger pipelines, the time required to complete all of the median estimated repairs are shown in Table 20. The table also shows median repair estimates and uncertainty. Repair estimates for the 24-inch JWC TL are shown in Table 21. These estimates assume one or two crews working in 12-hour shifts. The number of crews available is limited by the current equipment owned by the City.

As shown in Table 20, if there is one crew per day, it is estimated that it may take a little over a month (34 days) to complete the median estimate of repairs to the existing backbone pipelines and an additional two and a half months (75 days) to complete the median estimate of repairs to the existing non-backbone distribution system. It is estimated that the median repairs for the JWC TL would take a little over a week (10 days) to complete. If there are two crews per day, it may take a little over two weeks (18 days) to complete the median estimate of repairs to the existing

backbone pipelines and an additional month (38 days) to complete the median repairs to the existing non-backbone distribution system. It is estimated the median repairs for the JWC TL would take a little under a week (5 days) to complete.

Assuming material equipment and crew availability, median estimate of repairs for the existing water system (City backbone and non-backbone as well as the JWC TL) can be completed in about 2 to 4 months (assuming 1 to 2 crews per day). However, given the regional impact of M9 earthquake and associated limitations, for planning purposes, we estimate that the pipeline repairs may be completed in about 3 to 6 months.

Table 20: Number of Days to Complete Pipeline Repairs for City Pipelines

System	Pipeline		Number of Estimated Repairs[2]	No. of Days to Complete Repairs[1,3]	
				1 Crew/Day[1]	2 Crews/Day[2]
Backbone (BB)	Raw Water Transmission Main	Lower Estimate	5	5	3
		Median Estimate	13	13	7
		Upper Estimate	38	38	19
	Backbone Distribution	Lower Estimate	13	8	4
		Median Estimate	37	21	11
		Upper Estimate	108	61	31
Non-BB	Distribution System	Lower Estimate	74	26	13
		Median Estimate	213	75	38
		Upper Estimate	616	216	108
TOTAL		Lower Estimate	91	39	20
		Median Estimate	263	109	56
		Upper Estimate	763	315	158

Note:

1. One crew shift is 12-hours
2. Based on conservative estimate of total repairs as discussed in Section 5.0.
3. Assumes 1 repair/crew/day for large diameter (12 inches or larger) pipelines and 3 repairs/crew/day for smaller diameter pipelines.
4. Backbone distribution repair estimates also include future backbone.
5. Repairs rounded to the nearest whole number, may differ slightly from values in previous tables.

Table 21: Days to Complete Pipeline Repairs for the 24-inch JWC Finished Water Pipeline

Pipeline		Number of Estimated Repairs[2]	No. of Days to Complete Repairs[1,3]	
			1 Crew/Day[1]	2 Crew/Day[1]
24-inch JWC TL	Lower Estimate	3	3	2
	Median Estimate	10	10	5
	Upper Estimate	28	28	14

Note:

1. One crew shift is 12-hours
2. Based on conservative repair estimate of total repairs as discussed in Section 5.0
3. Assumes 1 repair/crew/day due to larger diameter pipeline.

6.3 OTHER FACILITIES

The 5 MG reservoir at the WTP has significant structural vulnerabilities. The potential damage is such that the reservoir may not be operational following an M9 CSZ earthquake. Due to limited available resources following such a large earthquake, it may take several months to repair and restore the reservoir to full operations. For this study, we have assumed 3 months to put the reservoir back into operation.

Potential damage to other facilities at the WTP is not expected to be catastrophic and is likely to be such that it could be repaired over time without significantly impacting treatment operations.

The other potentially significant impact to the City's facilities could be damage to the Equipment Building and the covered storage structure, which could impair the City's ability to immediately mobilize its repair crews.

6.4 MUTUAL AID

Oregon Water/Wastewater Agency Response Network (ORWARN) has 118 Oregon water and wastewater utilities. ORWARN member utilities provide voluntary assistance to each other during an emergency incident. In case of a natural or manmade hazard, ORWARN member utilities provide emergency services in the form of personnel, equipment, and materials. Due to the regional nature of the CSZ earthquake with impacts from Vancouver B.C. to parts of northern California, it is unlikely that any of the geographically closest ORWARN member utilities would be able to provide assistance to the City immediately following the M9 CSZ earthquake.

Consideration should be given to the interstate Emergency Management Assistance Compact (EMAC), which is a national interstate mutual aid agreement that enables states to share resources during times of disaster. EMAC is administered by the National Emergency Management Association (NEMA). Because EMAC is an interstate agreement, it can only be established by the state. However, once established, the City will be able to rely on aid from utilities unlikely to be significantly impacted by the Cascadia event. Some of the major water utilities in California that are unlikely to be impacted by the Cascadia event, such as the Los Angeles Department of Water and Power (LADWP), San Francisco Public Utilities Commission (SFPUC), East Bay Municipal Utility District (EBMUD), Municipal Water District of Orange County (MWDOC), and Contra Costa Water District (CCWD), can provide substantial aid.

Structural and traffic conditions of the inter-state transportation network following a major earthquake on the CSZ should be considered in planning for the arrival of out-of-state assistance. Several transportation methods, including highway, rail, water, and air should be considered as possible means of delivering materials, equipment, and workers to the City. For planning purposes, multiple alternative transportation

mechanisms should be considered due to likelihood of damage to the airport, roads, bridges and docks.

6.5 POTENTIAL IMPEDIMENTS TO POST-EARTHQUAKE REPAIR

The City has limited resources available for post-earthquake repair and does not have sufficient material stockpiled to complete the estimated repairs, which will need to be special ordered and shipped. During normal business conditions, it may take about one business week to procure and ship material and after the CSZ, this time is likely to increase significantly.

Damage to the transportation system is also a significant impediment to timely restoration of the City's water system. A detailed assessment of the impact of transportation infrastructure restoration of the water system was beyond the scope of this study.

It is expected that there will be numerous citizen and customer call-ins reporting leaks and breaks, with multiple calls reporting the same damage. This will likely overwhelm the City's system for handling leak calls and dispatching repair crews. In addition, there is a strict protocol for documentation and repair of earthquake-related damage to obtain reimbursements from Federal Emergency Management Agency (FEMA). It is our understanding that the City does not currently have established procedures for documentation that meets FEMA reimbursement requirements.

6.6 EXISTING SYSTEM RECOVERY TIME

Based on our median estimates of repair times and the City's ability to restore system to pre-earthquake levels, it may take much longer compared to the TSoRs in the ORP. Our estimate of time required to bring the system back to its pre-earthquake condition compared to ORP's TSoRs is presented in Figure 29. The figure shows that in its existing state, the City's system would not meet the ORP's TSoRs.

CSZ M_w 9.0 Event Occurs

CSZ M_w 9.0 Event Occurs

Timeline

ORP Category	CFG Assets	0 - 24 hours	1 - 3 days	3 - 7 days	1 - 2 weeks	2 weeks - 1 month	1 - 3 months	3 - 6 months
Potable water available at supply source (WTP, wells, impoundment)	1. RWTM from Stringtown Bridge to WTP 2. WTP facilities supporting treatment function 3. 24-inch JWC TL	20 - 30% operational	50 - 60% operational		80 - 90% operational	CFG 90% Recovery Time Est. Range		
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational	1. First-tier backbone distribution pipelines 2. 5MG reservoir at WTP	80 - 90% operational			CFG 90% Recovery Time Est. Range			
Water supply to critical facilities available	1. All backbone pipelines 2. David Hill Reservoir	50 - 60% operational	80 - 90% operational			CFG 90% Recovery Time Est. Range		
Water for fire suppression--at key supply points	1. FGFR fire department capability to utlize alternative water sources to suppress fires 2. David Hill Reservoir continued operation 3. 5MG WTP Reservoir continued opration	80 - 90% operational					CFG 90% Recovery Time Est. Range	
Water for fire suppression--at fire hydrants	1. All pipelines required to supply hydrants (most of distribution system)			20 - 30% operational	50 - 60% operational	80 - 90% operational	CFG 90% Recovery Time Est. Range	
Water available at community distribution centers/points	1. Backbone distribution pipelines		50 - 60% operational	80 - 90% operational	CFG 90% Recovery Time Est. Range			
Distribution system operational	1. All transmission and distribution pipelines 2. All pump stations		20 - 30% operational	50 - 60% operational	80 - 90% operational		CFG 90% Recovery Time Est. Range	

Figure 29: Existing System Estimated Recovery Time

7.0 MITIGATION OPTIONS

The City is located in an area of moderate seismic hazard and would be impacted by earthquake-induced ground shaking, liquefaction and landslides in an M9 earthquake on CSZ. The City could also be impacted by an earthquake on the nearby Gales Creek fault, which poses a surface fault rupture hazard in addition to strong shaking, liquefaction and landslides. However, the probability of a Gales Creek earthquake is low compared to an M9 earthquake on CSZ. Therefore, this report's primary focus is on the M9 earthquake.

Although the overall seismic hazard in the City is moderate, the risk of significant service interruption in water supply is high given the use of seismically vulnerable pipeline construction. The risk is further exacerbated by the regional nature of the CSZ earthquake. Areas designated as having very little and greater liquefaction severity are the most likely to require repairs of leaking or broken pipes. While some pipeline breaks may occur outside of this zone, it is our opinion that targeting the most vulnerable cast iron pipelines in areas with very little and greater liquefaction hazards is a cost-effective solution to improve the performance of the transmission and distribution system.

We estimate that in its existing state, it may take between 3 and 6 months following an M9 earthquake to bring the entire system back to its pre-earthquake condition. The estimated time range to restore various components of the system as they relate to the ORP's TSoR is shown in Figure 29. As shown in the figure, the range is broad and should be treated as a planning level estimate.

A list of recommendations to improve system performance in an M9 CSZ earthquake is developed as part of this report. The recommendations are developed with the intent that there is reliable supply of water for emergency use and firefighting immediately following the earthquake and that the water system for daily use and economic activity is restored in a reasonably short time.

7.1 BACKBONE

A system backbone is critical to collect and treat raw water and deliver treated water to the distribution network. Following the ORP's TSoR, the backbone system components should be 80 to 90 percent operational within 24 hours after an earthquake. Capital improvement projects to achieve this level of service are described in terms of first and second-tier improvement priorities. Completion of the first-tier backbone improvement projects will allow the City to draft emergency water from Gales Creek and distribute water to much of the City. Completion of the second-

tier backbone improvement projects will also allow the City to collect raw water from the Clear Creek watershed with additional storage at the David Hill Reservoir. The backbone system as defined in this study is shown in Plate 1.

7.1.1 First-Tier Backbone

Components of the first-tier backbone include:

- RWTM from the Stringtown Road Bridge to the WTP
- City WTP, including the 5 MG WTP Reservoir
- 24-inch JWC TL
- A treated water backbone pipeline network within the City

7.1.1.1 RWTM from Stringtown Road Bridge to the WTP

The first-tier backbone RWTM between the Stringtown Road Bridge and the WTP consists of about 1.8 miles of 16-inch CCP pipeline. Approximately 1.2 miles (67 percent) of the RWTM, from Stringtown Bridge to the raw water pump station, lies within an area of very little and greater liquefaction hazard. Because the 16-inch RWTM is an older pipeline and is critical for the water supply, we recommend that the City consider replacing sections of the pipeline within areas of very little and greater liquefaction hazard.

Butt-welded steel pipelines have historically been considered to be highly reliable in resisting large PGDs. In addition, recent testing at Cornell University (Stewart et al., 2015; Pariya-Ekkasut et al., 2017) has shown that seismic-resistant ductile iron pipes, such as US Pipe Ductile Iron TR-XTREME or Kubota Earthquake-Resistant Ductile Iron, also perform well in conditions where large ground deformations may occur. We recommend replacing the existing first-tier backbone with seismic-resistance ductile iron pipes or welded steel pipes in areas of very little and greater liquefaction hazards. For areas where there is no liquefaction potential (confirmed through future geotechnical evaluations), pipelines that are generally used for water systems in competent soils can be used.

Very limited subsurface information is available along the RWTM alignment. It is recommended that prior to a pipeline replacement program, a geotechnical study be performed to investigate subsurface conditions and characterize the soil's susceptibility to liquefaction. A geotechnical study could substantially reduce the length (and cost) of pipeline replacement.

The current RWTM alignment is close to an existing landslide near Forest Glen Park. City's maintenance staff have indicated that the transmission line near the park has been repaired previously, which suggests ongoing landslide activity. The landslide

hazard area is relatively small and could be avoided as part of a pipeline replacement program. We recommend an additional 500 feet (0.1 mile) of the RWTM be replaced and re-routed away from the landslide near Forest Glen Park.

Seismic improvement of this section of RWTM will allow water to be drafted from Gales Creek using the blind flange tee at the Stringtown Road Bridge crossing. Pumping from Gales Creek would require the City to purchase a submersible pump and backup power supply that could begin pumping water shortly after an earthquake. A backup power supply should also be installed at the raw water pump station to transport water to the WTP.

7.1.1.2 WTP and 5MG Reservoir

The 5MG WTP Reservoir is critical to provide treated finished water to the City. A separate recently completed detailed structural evaluation of the 5 MG reservoir recommended a complete replacement or retrofit of the WTP column and column footings. Simplified calculations performed for this study show that in addition to the columns, the walls also do not meet seismic demands for a continued operation performance criteria. Therefore, we recommend that the City considers a retrofit or replacement of the reservoir.

7.1.1.3 24-inch JWC TL

The 24-inch JWC TL pipeline is approximately 1.6 miles long. Approximately 1.3 miles (81 percent) lies in an area of very little and greater liquefaction hazard. The 24-inch JWC TL provides a redundant source of treated water supply. However, this redundant supply is only available if the Fern Hill Reservoirs and the pipelines from the Fern Hill reservoirs to the JWC WTP are operational following a CSZ event. A seismic resiliency study of these elements was outside of our scope of work. If it can be established that water supply from JWC is reliable, we recommend replacement of JWC TL in areas of very little and greater liquefaction hazard with seismic-resistant ductile iron or welded steel pipes for a reliable transmission of water to the City.

Limited subsurface information is available along the JWC alignment. We recommend a geotechnical study be performed to investigate subsurface conditions and characterize the soil's susceptibility to liquefaction prior to pipeline replacement.

7.1.1.4 10th Avenue Control Station

The 10th Avenue Control Station is part of the first-tier backbone because it connects the JWC TL to the City's distribution system. The station may be susceptible to liquefaction. A detailed evaluation of liquefaction hazard and structural response to meet the ASCE 41-17 Immediate Occupancy performance level is recommended.

7.1.1.5 First Tier Backbone Distribution System

The first-tier backbone distribution system within the City is approximately 8.0 miles long and consists of about 5.8 miles of cast iron pipelines and 2.2 miles of ductile iron pipelines. A total of approximately 4.0 miles (50 percent of total) of cast iron pipelines are in areas identified as having very little and greater liquefaction hazard. Approximately 29 repairs (median estimate) are estimated in the first-tier backbone distribution system with a majority of these repairs (median estimate of 25) in the seismically vulnerable cast iron pipelines. Since the TSoR for the backbone is 90 percent operational within 24 hours following an earthquake, we recommend the City consider replacing the cast iron pipelines in the backbone distribution system with seismic resistant pipeline material. Within the backbone distribution system, multiple locations cross areas of liquefaction hazard, and until the cast iron pipelines are replaced, the City should consider installing isolation valves at various pressure zones to isolate damage if some segments of the backbone distribution system fail.

Table 22 provides a summary of the recommended first-tier backbone improvements.

Table 22: First-Tier Backbone Capital Improvement Projects

System component:	Description[1,2]
RWTM pipeline	
Geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length
Structural Study	Detailed structural evaluation of the Stringtown Road Bridge to assess potential impacts to the suspended RWTM and evaluate between bridge retrofit or a new pipeline crossing
Pipeline replacement	Estimated pipeline replacement: 1.2 miles
Forest Glen Park re-route	Pipeline replacement and re-route: 500 feet (0.1 miles)
Submersible pump, power supply, and backup power supply at raw water pump station	Infrastructure needed to draft water from Gales Creek at Stringtown Road Bridge
City WTP	
5MG WTP Reservoir	Recommendations in a separate study[3]. As recommended in this study retrofit or replace reservoir.
Structural Studies	More detailed study to assess Life Safety performance criteria for the Office Building and assess the anchorage of the electrical cabinet (part of the generator)
24-inch JWC TL	
Geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length
Pipeline replacement[4]	Estimated pipeline replacement: 1.3 miles
10th Avenue Control Station	Recommend a detailed liquefaction and structural evaluation to meet ASCE 41-17 Immediate Occupancy (structural and non-structural) performance level.
Backbone distribution system	Estimated pipeline replacement: 4.0 miles
Isolation valves	Addition of isolation valves at strategic locations within the first-tier backbone to minimize the risk of uncontrolled release of water from damaged pipelines. Recommend a study to identify location and type (manual, remote operated or seismically-triggered) of valves. This includes valves at the reservoirs to minimize the risk of uncontrolled release of water.

Note:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.
2. It is assumed that the pipelines would be replaced with the same diameter pipeline.
3. OBEC, 2018
4. Up to 50% of the cost for the 24-inch JWC TL replacement may be paid for the city of Hillsboro.

7.1.2 SECOND-TIER BACKBONE

Components of the second-tier backbone include:

- Raw water intake structures and collection pipelines
- RWTM upstream of the Stringtown Road Bridge
- David Hill Reservoir
- Extension of the first-tier backbone distribution network within the City

Many historic and prehistoric landslides have been mapped within the Clear Creek watershed near the raw water intake structures and RWTM. Some of the mapped landslides are currently only marginally stable and could potentially become unstable and fail in an earthquake. The Smith Creek, Deep Creek, Thomas Creek, and Roaring Creek raw water intake facilities are downslope of large, potentially unstable landslides. These creeks could experience increased sediment loads or could temporarily become dammed by landslides following an earthquake. The Clear Creek raw water intake structure is generally outside the area of mapped historic landslides. Based on its location, turbidity may be less severe at the Clear Creek raw water intake structure than at the other intake structures.

Raw water collected at the intake structures is fed through the collection lines to the RWTM. The second-tier backbone collection lines and RWTM consists of about 1.2 miles of cast iron pipelines and about 6.0 miles of CCP. Both cast iron pipelines and CCP are vulnerable to earthquake-triggered landslides. Figure 30 shows areas of high landslide susceptibility and historic landslide deposits near the second-tier backbone RWTM. About 1.9 miles of the second-tier backbone lies within an area of high landslide hazard or within a historic landslide deposit.

At a regional scale, the depth, extent, and deformation of earthquake-triggered landslides is highly uncertain. Additional site-specific geotechnical investigations are recommended along the alignment designated as high hazard in Figure 30. Depending on the depth and extent of the possible landslides, capital improvement projects may range from re-routing the pipeline alignment around the landslide, mitigating the landslide, or microtunneling under the landslide. Future investigations should focus on characterizing the subsurface conditions, defining the extent and magnitude of potential landslides, and recommending seismic mitigation alternatives. For planning, it can be assumed that about 40 percent of the second-tier backbone pipelines within the area of high landslide hazard will require microtunneling under active landslides and 60 percent will require pipeline rerouting and replacement. A geotechnical investigation with site-specific landslide hazard assessments could substantially reduce the scope and cost of the second-tier backbone RWTM improvement project.

There are some segments of the RWTM from Clear Creek to the Gales Creek Cemetery that are susceptible to both liquefaction and landslide hazards. Between the Gales Creek Cemetery and the Stringtown Road Bridge, approximately 3.5 miles of the second-tier backbone RWTM lies within an area of very little and greater liquefaction hazard. About 0.2 miles of the Gales Creek fire line extension also lies within an area of very little and greater liquefaction hazard. Similar to the first-tier backbone RWTM, we recommend replacing backbone pipelines in areas of very little and greater liquefaction hazard with seismic-resistant ductile iron or welded steel pipes. Very limited subsurface information is available along the RWTM alignment. Because of the lack of subsurface information, we recommend a geotechnical investigation be performed prior to planning a pipeline replacement program. Such a program could substantially reduce the length of pipeline replacement.

The RWTM crosses Gales Creek at the Stringtown Road Bridge. Lateral spreading along the banks of Gales Creek could impact the bridge and a detailed structural evaluation of the bridge is recommended. Preliminary assessment by ODOT (1995) identified possible deficiencies in the substructure. The study should also evaluate the feasibility of bridge retrofit versus a separate new crossing of the pipeline.

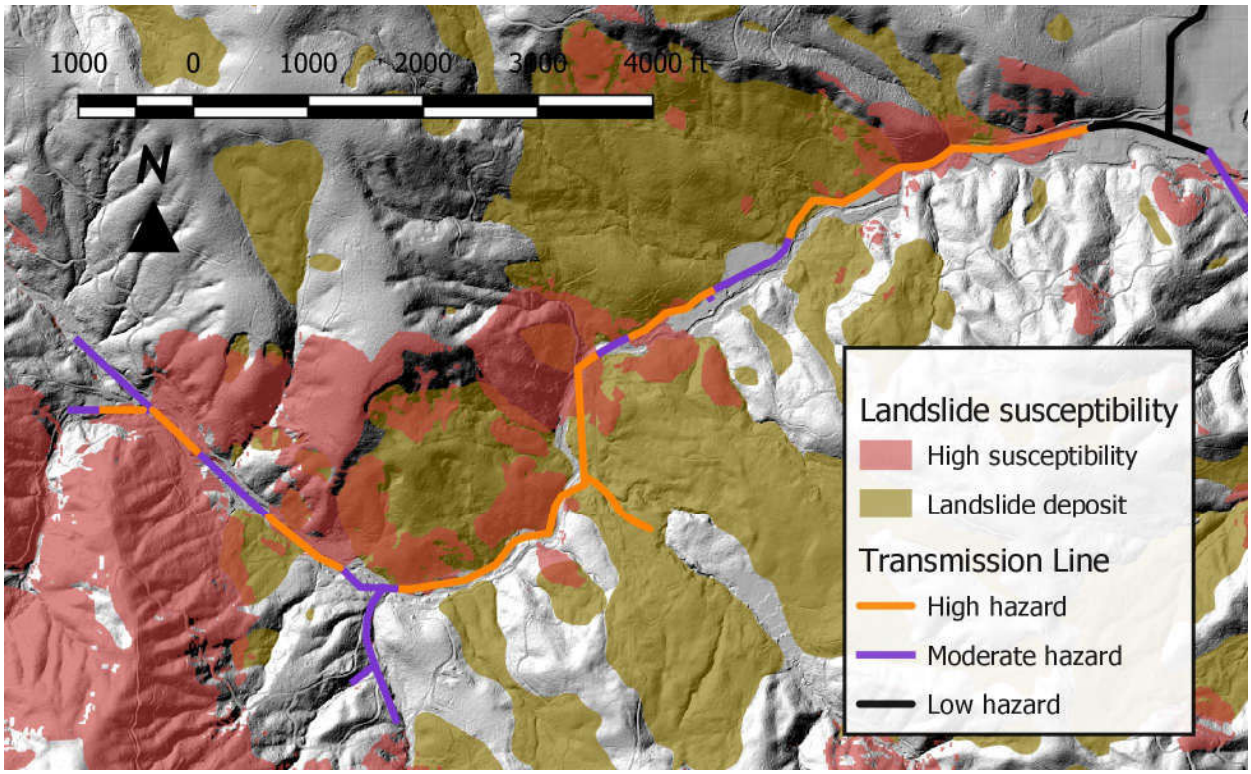


Figure 30: Landslide Hazards along RWTM within the Clear Creek Watershed

The second-tier backbone also includes the David Hill Reservoir. Our assessment based on simplified calculations and conservative assumptions shows that the perimeter

walls of the David Hill Reservoir do not meet the estimated seismic demands. Therefore, it is recommended that a more detailed seismic analyses of the David Hill Reservoir be performed to assess the potential for significant damage resulting in the loss of water in an M9 earthquake. A portion of the second-tier backbone distribution pipeline near the intersection of NW David Hill Road and the service road leading to David Hill reservoir is also at risk from earthquake-triggered landslide hazard. This area is approximately 400 feet-long and appears to be related to an oversteepened road cut. We recommend mitigating the landslide or re-routing the pipeline around the potential landslide.

The second-tier water distribution backbone consists of about 2 miles of cast iron and about 2.4 miles of ductile iron pipelines. A total of about 1 mile of the second-tier backbone distribution pipelines lies within an area of very little and greater liquefaction hazard. We recommend that approximately 0.8 miles of cast iron pipelines in areas of very little and greater liquefaction hazard be replaced with seismic resistant pipeline material. In the interim, the City should consider installing isolation valves at various pressure zones (backbone and distribution system) to isolate damage and minimize the risk of uncontrolled release of water. A summary of the recommended second-tier backbone improvements is provided in Table 23.

Table 23: Second-Tier Backbone Capital Improvement Projects

System component:	Description
RWTM pipeline	
Clear Creek geology and geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length
Clear Creek to Gales Creek Cemetery pipeline replacement	Estimated pipeline replacement: 1.9 miles Mitigation method defined following a geotechnical investigation
Gales Creek geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length
Gales Creek Cemetery to Stringtown Road Bridge pipeline replacement	Estimated pipeline replacement: 3.7 miles
Stringtown Rd. Bridge pipeline crossing structural assessment	Seismic assessment of the bridge such that the pipeline suspended from the bridge is not damaged or a study to consider new pipeline creek crossing separate from the bridge
David Hill Reservoir	Structural evaluation
Backbone distribution system	Estimated pipeline replacement: 0.8 miles
System-wide	Isolation valves at strategic locations within the second-tier backbone and non-backbone system to minimize the risk of uncontrolled release of water from damaged pipelines. Recommend a study to identify location and type (manual, remote operated or seismically-triggered) of valves. This includes valves at the reservoirs to minimize the risk of uncontrolled release of water.

7.2 DISTRIBUTION PIPELINES

The non-backbone distribution pipeline system consists of approximately 25.3 miles (35.5 percent) of cast iron and 40.9 miles (57.5 percent) of ductile iron pipelines, of which 15.5 miles of cast iron and 25.1 miles of ductile iron pipelines are located in areas of very little and greater liquefaction hazard. Median estimate of repairs in different liquefaction susceptibility zones is summarized in Table 24.

Table 24: Median Estimate Non-Backbone Distribution Pipelines Repairs

Pipeline Type	Length (mi)[1]	Pipelines <12-inch in Liquefaction Severity Zones[6]				Repairs[6] (<12-in)	Repairs[6] (≥12-in)	Total Repairs[6]
		No Liq.	Very Little Liq.	Marginal Liq.	Moderate Liq.			
Cast iron[2]	25.3	1	47	55	2	106	0	106
Ductile iron[3]	40.9	1	43	35	2	81	5	86
Other[4]	4.9	0	12	9	0	22	0	22
Total[5]	71.1	2	102	99	5	208	5	213

Note:

1. Pipeline lengths are based on information in the City's GIS database provided on June 5, 2018, which have since been updated.
2. Cast Iron pipe includes pipelines marked as CIP in City GIS files
3. Ductile Iron pipe includes pipelines marked as DIP City GIS files
4. Other include pipelines marked as C900, (PVC), PVC, COPPER (Copper), GALV/GALVINIZED (Galvanized Steel), GI (Galvanized Iron), POLY (Polyethylene), STEEL (Steel), and unspecified in City GIS Files
5. Minor difference in total repairs due to rounding.
6. Repairs rounded to the nearest whole number.

As shown in Table 24, seismically vulnerable cast iron pipelines that constitute approximately 35.5 percent of all pipelines in the system and contribute to about half of all pipeline repairs, and ductile iron pipelines that constitute approximately 57.5 percent of all pipelines have about 40 percent of median estimated repairs. Assuming that the City can perform three repairs/day (subject to material availability) for pipelines sizes less than 12 inches and one repair/day for larger sizes, it could take about two and a half months to perform a median estimate of 213 repairs with one crew working 12-hour shifts. Additional crews will reduce the time to restoration to a little over one month with two crews working 12-hour shifts.

To meet the ORP goal of bringing the distribution system back to pre-earthquake levels in one to two weeks would require a substantial investment by the City in terms of distribution system pipeline replacement. It is our recommendation that the City considers replacement of cast iron pipelines in very little and greater liquefaction areas as part of a seismic improvement program. Priority should be given to replacement of large diameter and older cast iron pipelines. In addition, the City should include liquefaction severity as one of the criteria in its long-term asset

management plan for pipeline replacement for non-cast iron pipelines so that older ductile iron and other pipelines in high liquefaction severity zones are replaced on a priority basis.

While this approach will not fully satisfy the ORP goals, the recommended system upgrades coupled with emergency operations planning will significantly improve the resiliency of the City's water system. To meet the ORP goal of bringing the distribution system back to pre-earthquake levels in one to two weeks would require a substantial investment by the City in terms of distribution system pipeline replacement.

It is recommended that within the liquefaction areas, the replacement pipelines should be designed to accommodate liquefaction-induced PGD. Depending on the magnitude of expected PGD, pipelines such as butt-welded steel pipes, earthquake resistant ductile iron, TR-XTREME, and restrained joint ductile iron pipelines can be selected during the design process.

Since the estimated repairs are a function of liquefaction, a refinement in the liquefaction hazard mapping within the City's service area is recommended. Liquefaction maps developed as part of this study are based on regional level assessment; therefore, they have inherent uncertainties and are generally conservative. We recommend that the City develops a long-term geotechnical program to maintain a central database of geotechnical investigations within the City's service area and use this information to periodically update liquefaction hazard maps using site-specific data. This will help in identifying the most vulnerable segments of the City's pipeline system.

8.0 RECOMMENDATIONS

Results of this study show that several key components of the water system are seismically vulnerable and could sustain significant damage in an M9 CSZ earthquake. Structures critical for the continued supply of water to the system have been identified as backbone facilities. TSoRs in ORP provide a target for the backbone structures to be 80 percent to 90 percent operational within 24 hours and for the entire system to be at 80 percent to 90 percent operational level within 1 month. In its current condition, we estimate the City will recover to 90 percent backbone operation in about 2 weeks to 1 month and 90 percent of the entire system in about 3 to 6 months. This estimate assumes that damage to 5MG WTP reservoir is such that it does not result in uncontrolled release of water. Repair time estimate can be significantly higher if damage to the reservoir is excessive. A replacement or seismic retrofit of the reservoir is, therefore, recommended, as discussed in OBEC (2018).

The total cost of all mitigations described in Section 7.0 could be significant. However, we believe many critical TSoR goals could be achieved at substantially lower costs. We propose two packages of mitigation options for the City to consider. Option 1 is a lower cost option designed to achieve TSoRs for the first-tier backbone and critical water supply elements. Option 2 is an extension of Option 1 and while it will not fully satisfy the ORP goals, the recommended system upgrades coupled with emergency operations planning will significantly improve the resiliency of the City's water system. To meet the ORP goal of bringing the distribution system back to pre-earthquake levels in one to two weeks would require a substantial investment by the City in terms of distribution system pipeline replacement.

8.1 MITIGATION OPTION 1: FIRST-TIER BACKBONE AND CRITICAL WATER SUPPLY

Access to water from the watershed and JWC following the M9 CSZ earthquake require extensive pipeline upgrades since the pipelines cross large areas of moderate liquefaction hazard. Alternatively, water could be drafted from Gales Creek using the blind flange tee at the Stringtown Road Bridge crossing. It is recommended that City invest in infrastructure required to reliably draft water from Gales Creek such as submersible pump and power supply that could begin pumping water shortly after an earthquake. To maintain a reliable pipeline from the Stringtown Road Bridge to the WTP, section of the existing RWTM pipeline between the bridge and WTP should be replaced with seismic-resistant pipe. Seismic deficiencies in the WTP should also be mitigated.

Leaks and breaks within the first-tier backbone distribution system may cause the system to temporarily lose pressure. Cast iron pipes in areas identified as having very

little and greater liquefaction hazard are at the highest risk of failing and we recommend replacing these pipes. Isolation valves should be installed near locations where pipelines cross areas of very little and greater liquefaction hazard to prevent uncontrolled release of water from damaged pipelines.

Table 25 provides a summary of Mitigation Option 1.

Table 25: Mitigation Option 1 Capital Improvement Projects

System component:	Description
Emergency pumping equipment	
Stringtown Road Bridge pump and power supply	Considerations should be given for a permanent pump station
Raw water pump backup power supply	
RWTM Pipeline from Stringtown Road Bridge to WTP	
Geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length.
Liquefaction zone pipeline replacement	Estimated pipeline replacement length: 1.2 miles.
Forest Glen Park re-route	Pipeline replacement and re-route: 500 feet.
WTP	
5 MG WTP Reservoir	Retrofit or replace reservoir.
Generator	Assess anchorage of the electrical cabinet and if needed, anchorage to prevent sliding and overturning.
First-Tier Backbone distribution system	Replace cast iron pipelines in very little and greater liquefaction severity zones. Replace cast iron pipelines in marginal and greater liquefaction zones (estimated pipeline replacement of 2.6 miles) as highest priority followed by cast iron pipelines in very little liquefaction severity zones (estimated pipeline replacement of 1.4 miles)
Public Works Office Building and Maintenance Bays	Detailed structural analysis of the Public Works Office Building to assess Life Safety performance criteria and to assess mechanical equipment and electrical panel anchorage.
Isolation valves	Isolation valves at strategic locations within the first-tier backbone to minimize the risk of uncontrolled release of water from damaged pipelines. Perform study to identify location and valve types (manual, remote operated or seismically-triggered).

As per ORP, the goal would be to implement these projects over a 50-year timeline. In order of priority, these projects include WTP reservoir retrofit, the RWTM pipeline mitigation and emergency pumping equipment, followed by backbone distribution system mitigation.

8.2 MITIGATION OPTION 2: FIRST-TIER BACKBONE, SECOND-TIER BACKBONE AND NON-BACKBONE DISTRIBUTION SYSTEM

Without mitigation, dozens of leaks and breaks could occur along the first- and second-tier backbone system and a couple hundred leaks and breaks elsewhere in the water distribution system.

To expedite the repair process, we recommend replacing all cast iron pipelines along the second-tier distribution backbone that are in areas designated as very little and greater liquefaction severity. These upgrades substantially reduce the risk of pipeline breaks along the backbone system and allow the City's resources to focus on repairing other aspects of the distribution system following an earthquake. We also recommend upgrading the 24-inch JWC TL to seismic-resistant pipe in areas designated as very little and greater liquefaction severity to achieve redundancy in supply.

A structural evaluation of the David Hill reservoir should also be performed as part of Mitigation Option 2. Backup power supplies should be installed at the David Hill and Watercrest Road pump stations to reliably supply water to the second-tier backbone.

We also recommend replacement of cast iron non-backbone distribution pipelines in very little and greater liquefaction areas, with priority given to replacement of large diameter and older cast iron pipelines. The City should also consider developing a long-term asset management plan for non-cast iron pipeline replacement of all distribution pipelines that considers liquefaction severity, as well as corrosion conditions and age of the pipelines, as part of the criteria for establishing replacement priorities.

Table 26 provides a summary of Mitigation Option 2, which also includes the mitigation projects in Mitigation Option 1. If Mitigation Option 2 is selected, priority should first be given to the Mitigation Option 1 projects.

Table 26: Mitigation Option 2 Capital Improvement Projects

Option 1 mitigation required before proceeding with Mitigation Option 2

System component:	Description
Second-tier backbone upgrades	Estimated pipeline replacement: 0.8 mile
RWTM from Watershed to Stringtown Road Bridge	
Structural Study	Detailed structural evaluation of the Stringtown Road Bridge to assess potential impacts to the suspended RWTM and, if needed, replacement or retrofit of Stringtown Bridge. Alternatively, constructing a new pipeline crossing separate from the bridge.
Geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length.
Pipeline Replacement	Replace RWTM from Watershed to Stringtown Road Bridge, based on the findings of the Geotechnical study. This could include approximately 1.9 miles of pipeline from Clear Creek to the Gales Creek Cemetery and approximately 3.7 miles of pipeline between the Gales Creek Cemetery and the Stringtown Road Bridge
10th Avenue Control Station	
Structural Evaluation	Recommend a detailed evaluation of liquefaction hazard and structural response be performed of the 10th Avenue Control Station to meet ASCE 41-17 Immediate Occupancy (structural and non-structural) performance level
Modify Pipe Penetrations	Due to the potential risk of liquefaction, it is recommended that flexibility be provided to the rigid pipe to wall and pipe to slab penetrations.
24-inch JWC **TL**	
Geotechnical investigation	Recommended for site-specific assessment of hazard to potentially reduce pipeline replacement length
Pipeline replacement	Estimated pipeline replacement length: 1.3 miles
David Hill reservoir seismic structural evaluation	Additional analysis could show the reservoir performance to be acceptable
Emergency power supply	
David Hill pump station	Provide emergency power at David Hill pump station
Watercrest Road pump station	Provide emergency power at Watercrest Road pump station
Non-backbone distribution pipelines	Replace cast iron pipelines in very little and greater liquefaction severity zones (15.5 miles). Additionally, develop a long-term non-cast iron pipeline replacement plan that considers liquefaction severity, corrosion, and age of pipelines.
System-wide	Isolation valves at strategic locations within the second-tier backbone and non-backbone distribution system to minimize the risk of uncontrolled release of water from damaged pipelines. Perform study to identify location and valve types (manual, remote operated or seismically-triggered).

8.3 OTHER NON-CIP MITIGATION CONSIDERATIONS

To improve the time of system restoration to pre-earthquake levels following an earthquake, we recommend stockpiling enough repair resources (pipe, clamps, etc.) for at least 10 workdays worth of repairs. Emergency equipment, including pumps,

backup power supply, and emergency water treatment facilities, should be fully tested on a biannual basis. Such tests may be incorporated into employee training and emergency response drills.

The City should also work to develop the EMAC program through the State of Oregon to secure mutual aid from utilities in California that are unlikely to be impacted by a CSZ event.

Other programs include anchoring and restraining all vital electrical and communication equipment. Finally, the City should consider developing long term plans to isolate the backbone from the distribution system.

Additional non-CIP considerations could help expedite recovery following an earthquake. These considerations are organized by priority and include:

Priority 1

- Establishing material procurement protocols and on-call contracts with suppliers for rapid delivery in an emergency.
- Working with the state government to establish EMACs.
- Developing a procedure to track calls and identify leaks.

Priority 2

- Developing and conducting annual training events for all City employees addressing 1) personal earthquake safety; and 2) City emergency response procedures following a major earthquake.
- Establishing protocols for all City employees, including repair crew members, to report to their respective City facilities following a major earthquake. Step-by-step logistics must be taken into account, such as minimizing the distance each repair crew member must travel from their residence to the assigned City facility.
- Establishing repair protocols that result in a permanent repair, rather than an initial temporary repair followed by permanent repair. This has multiple benefits of cost savings and FEMA reimbursement.

Priority 3

- Developing and maintaining regularly updated utility maps to minimize the need to locate utilities in an emergency.

- Since the estimated repairs are a function of liquefaction, a refinement in the liquefaction hazard mapping within the City's service area is recommended.

We recommend that the City develops a long-term program to maintain a central database of geotechnical investigations within the City's service area and use this information to periodically update liquefaction hazard maps using site-specific data. For example, the City could implement a system that includes sharing of geotechnical investigations conducted for development sites as part of the permitting process, as is done with other municipalities. This will help in identifying the most vulnerable segments of the City's pipeline system.

Simple actions during the repair process after an earthquake could improve the recovery rate. Such post-event actions include:

- Locating smaller leaks using sonic sensors or other methods once the obvious breaks and leaks have been located.
- Isolating breaks and major leaks.
- Confirming leak.
- Prioritizing repairs.
- Documentation to help expedite cost recovery from FEMA.
- Detailed documenting of repairs, photos, parts, and labor.

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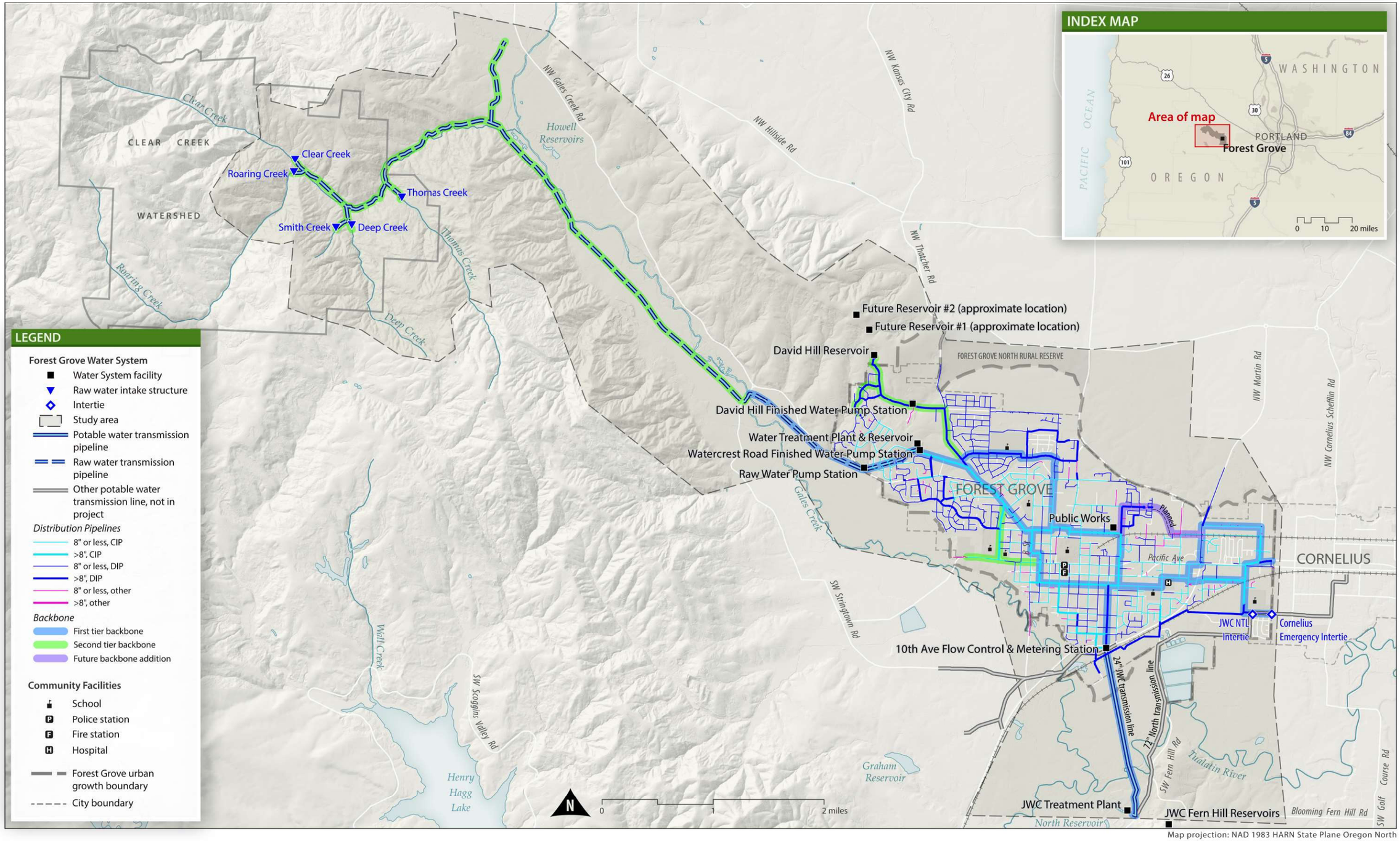
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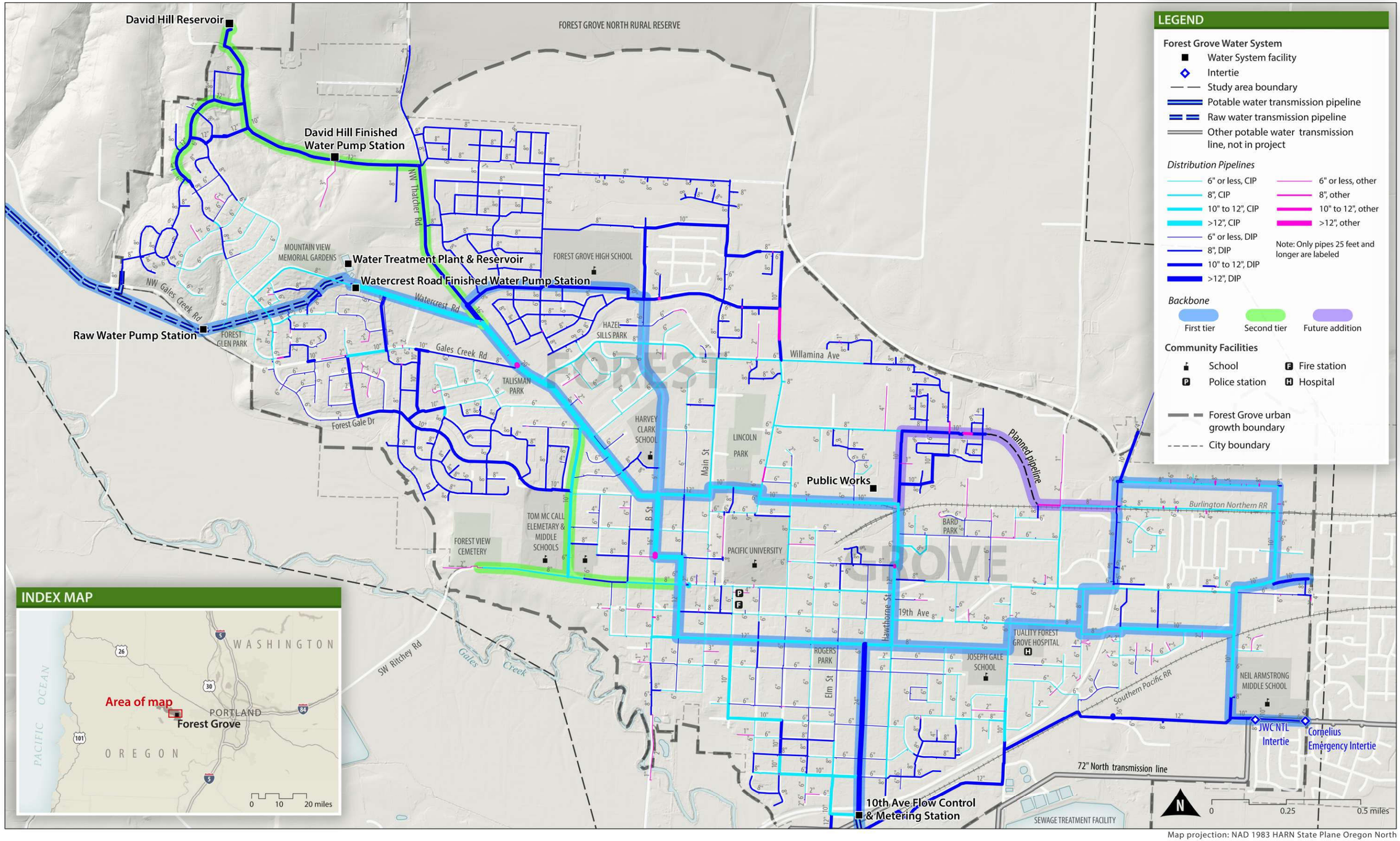
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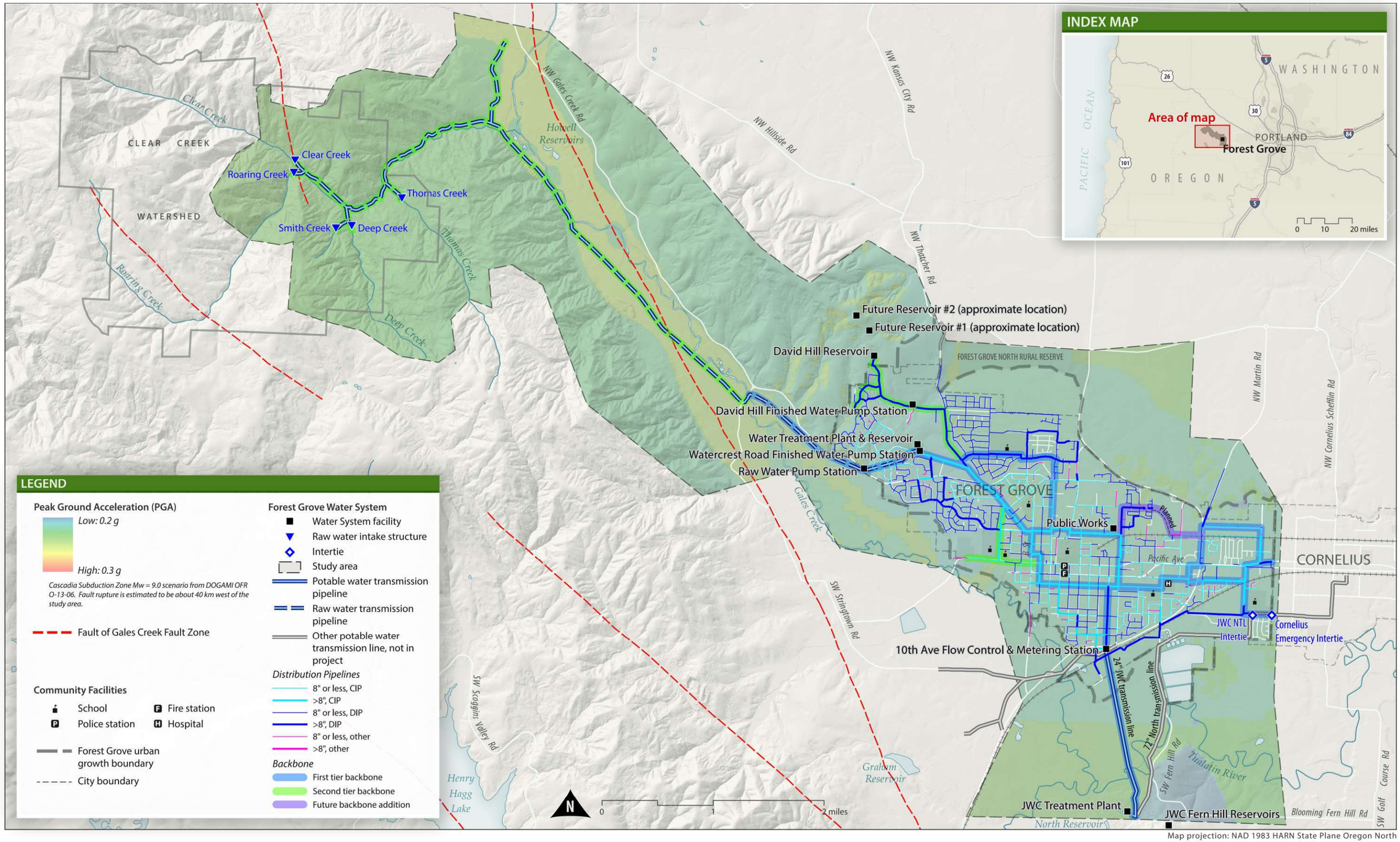
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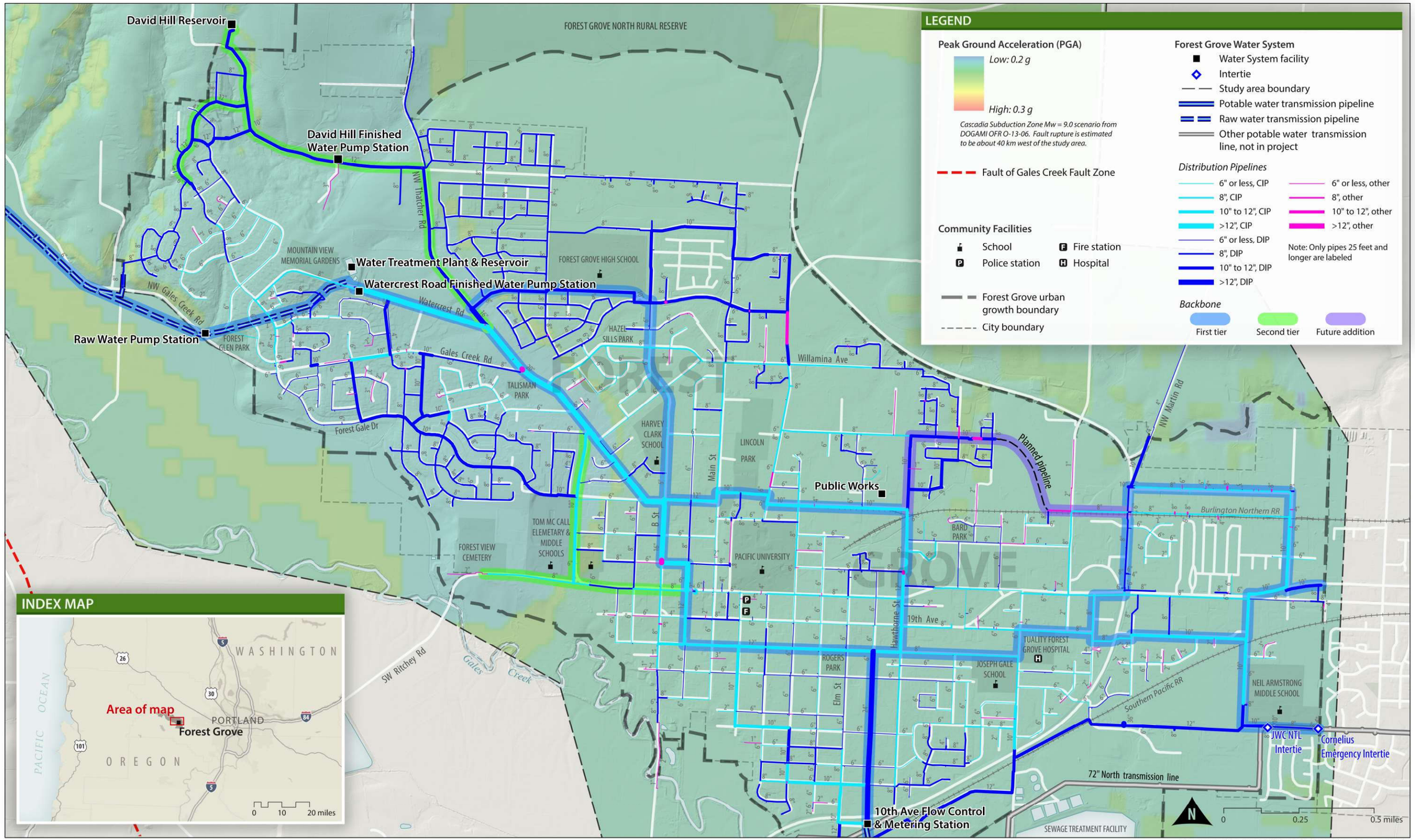
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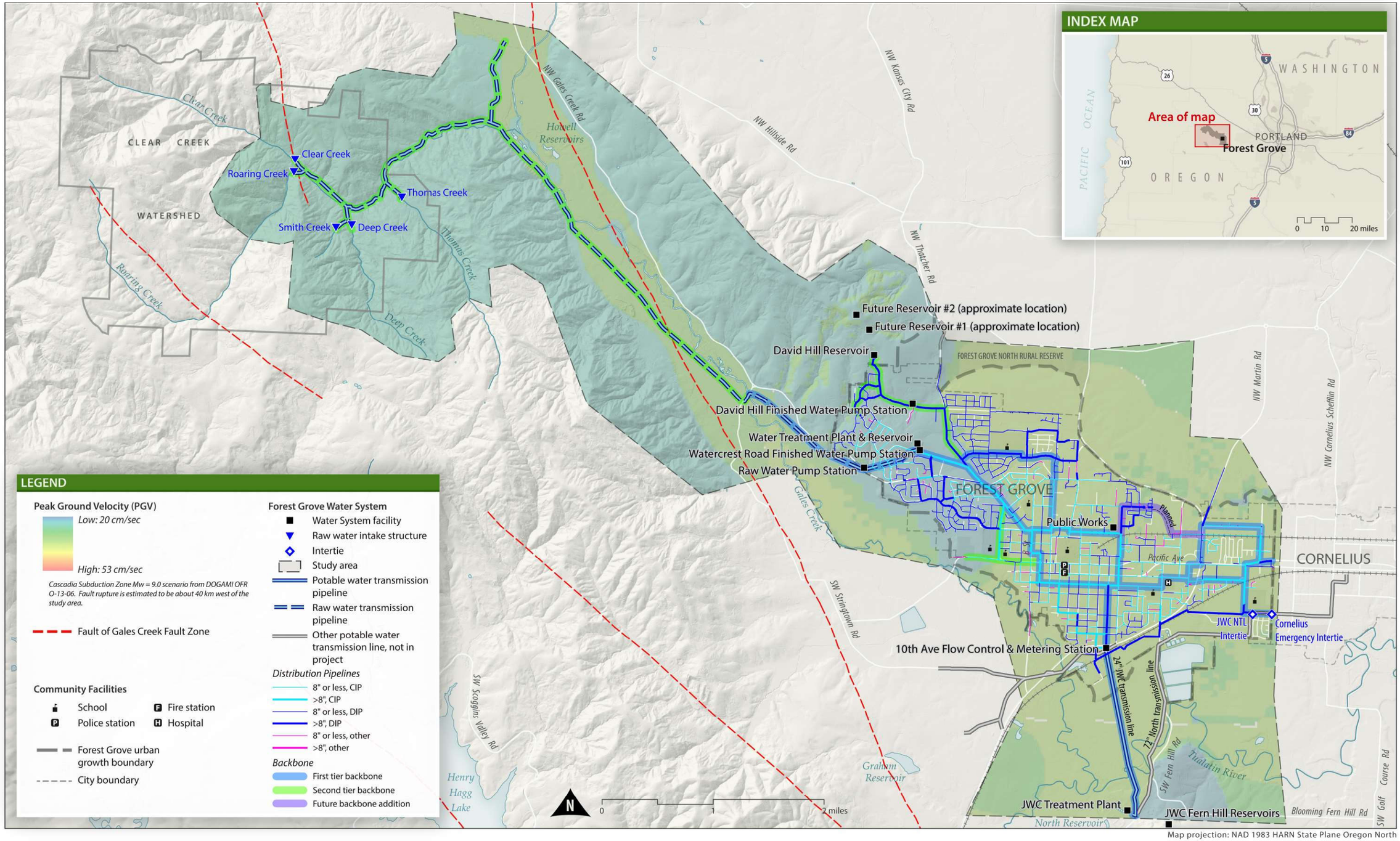
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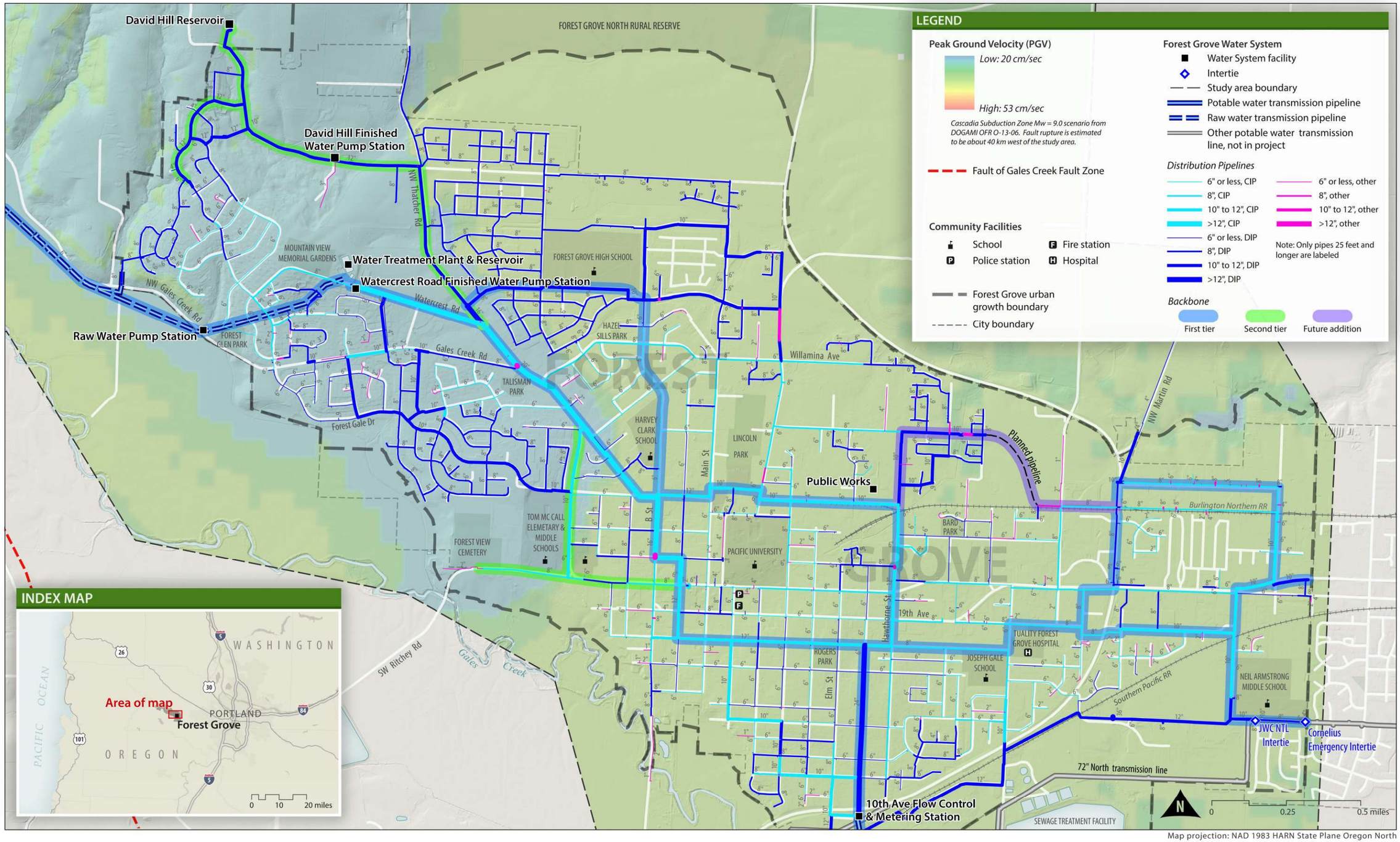
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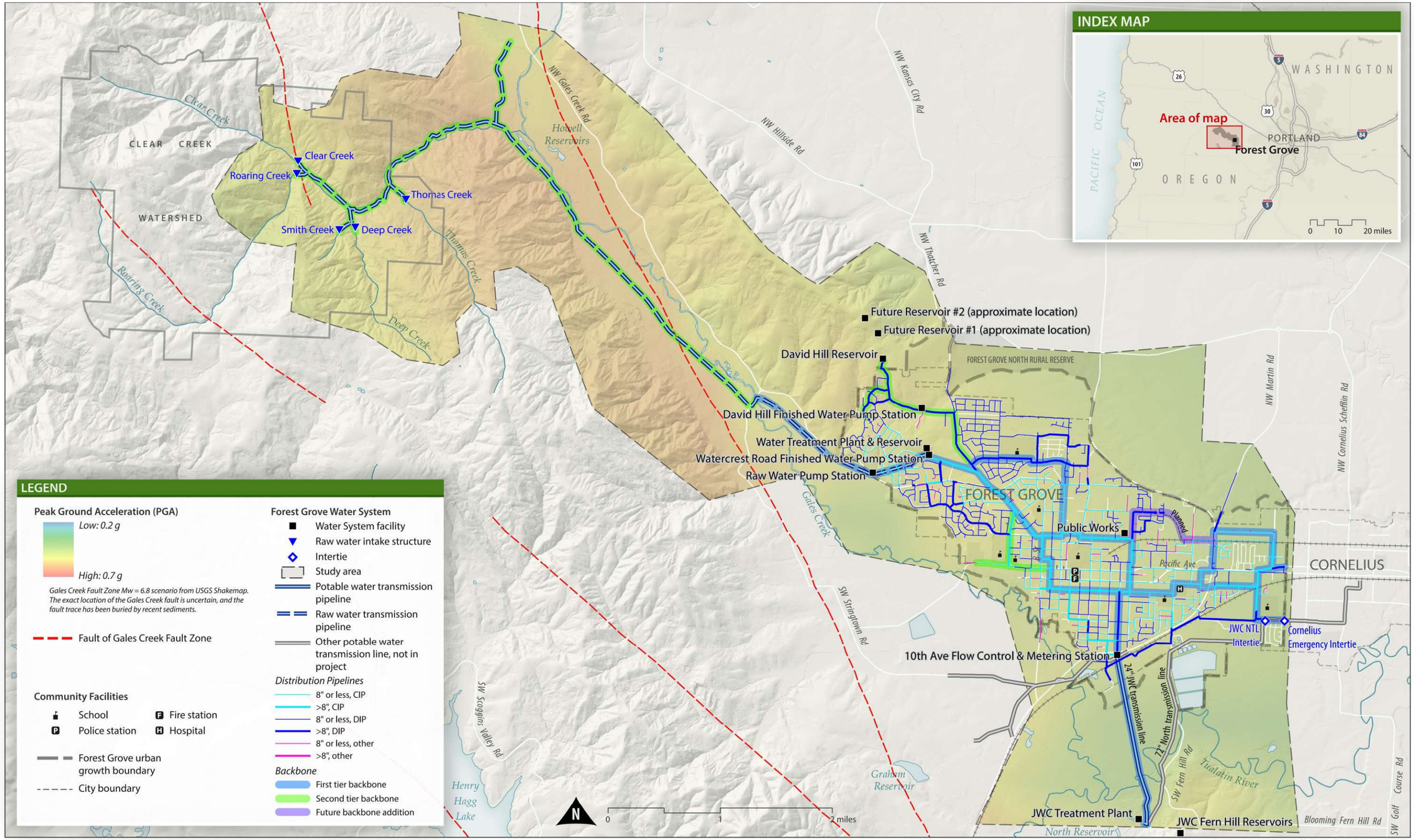
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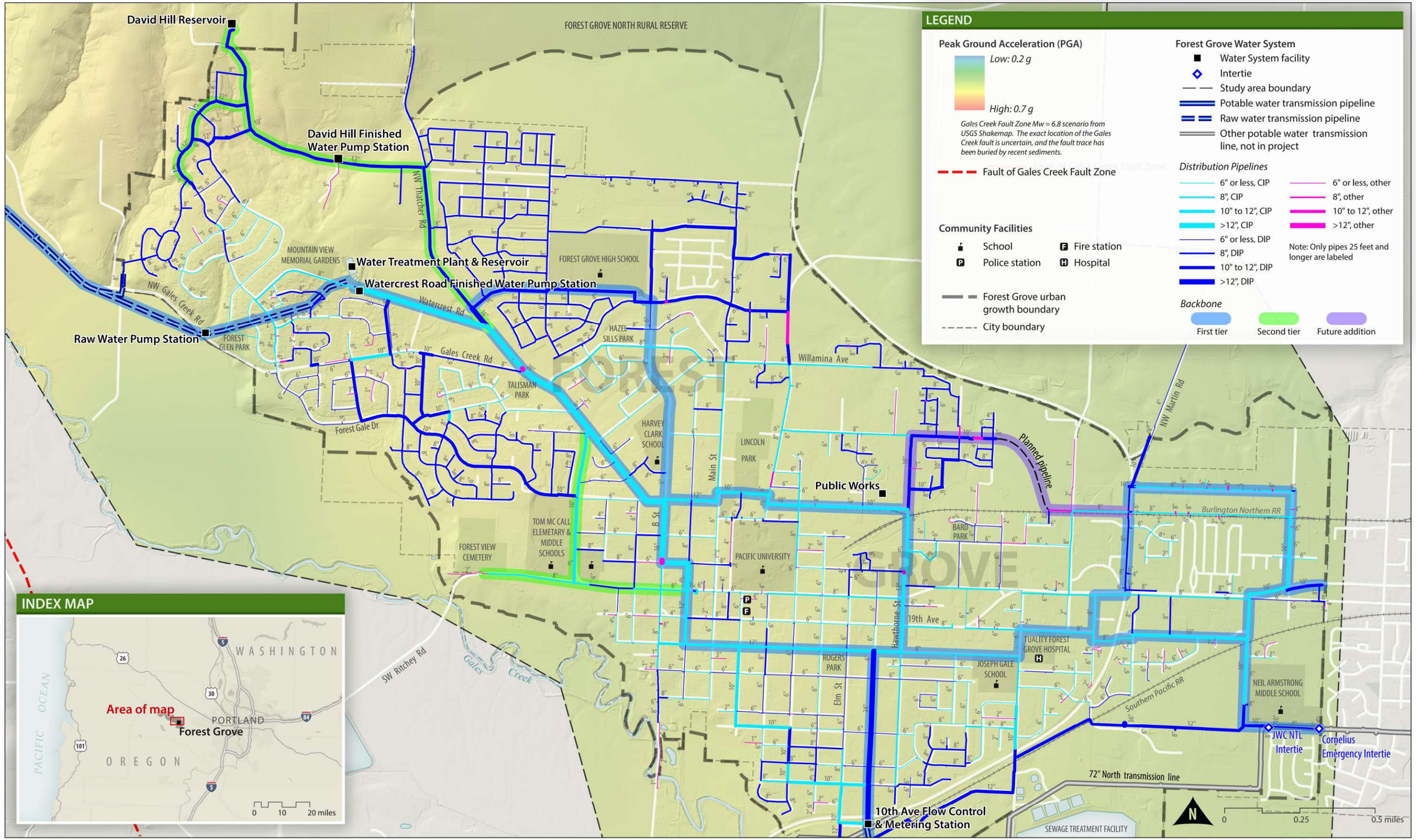
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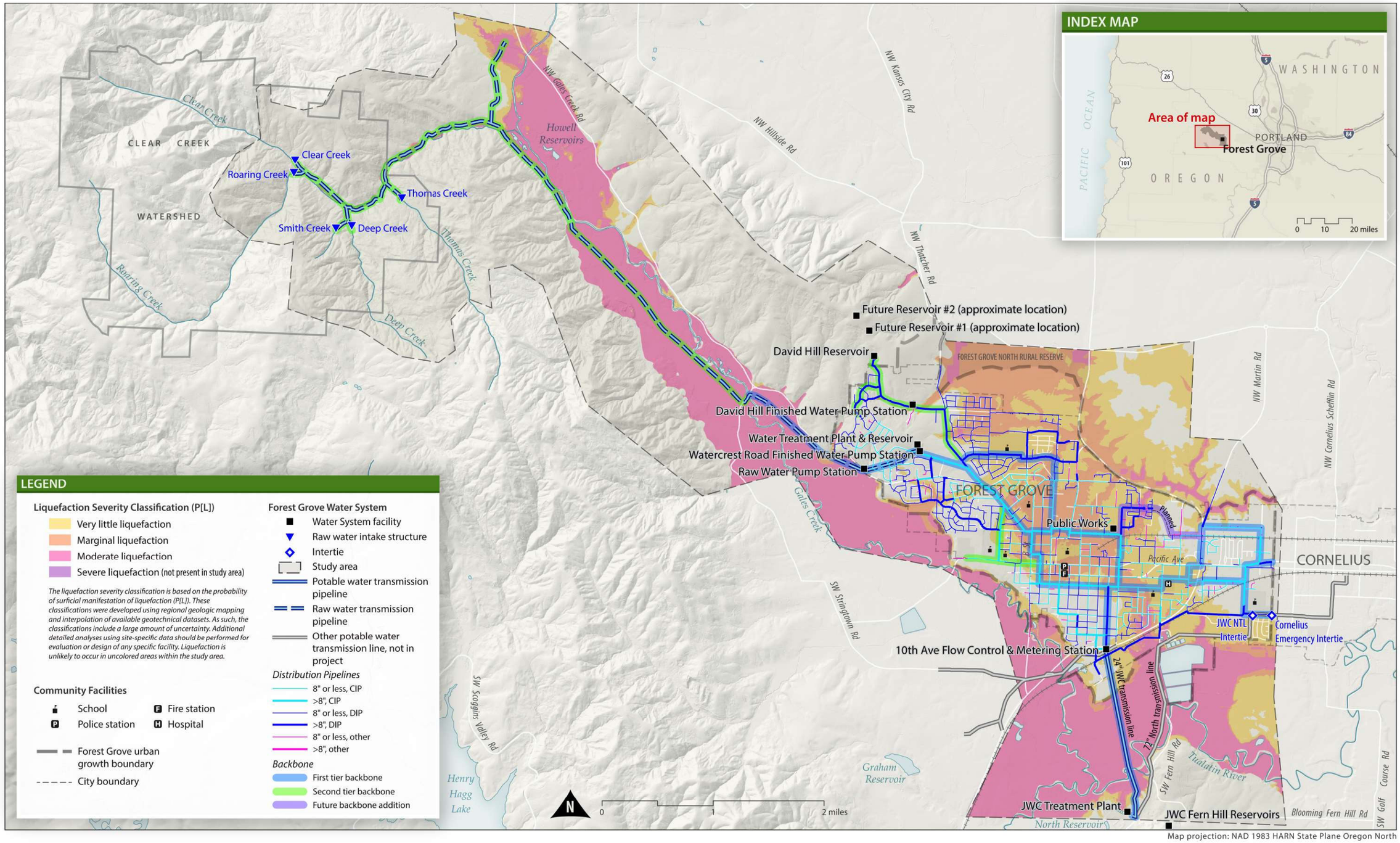
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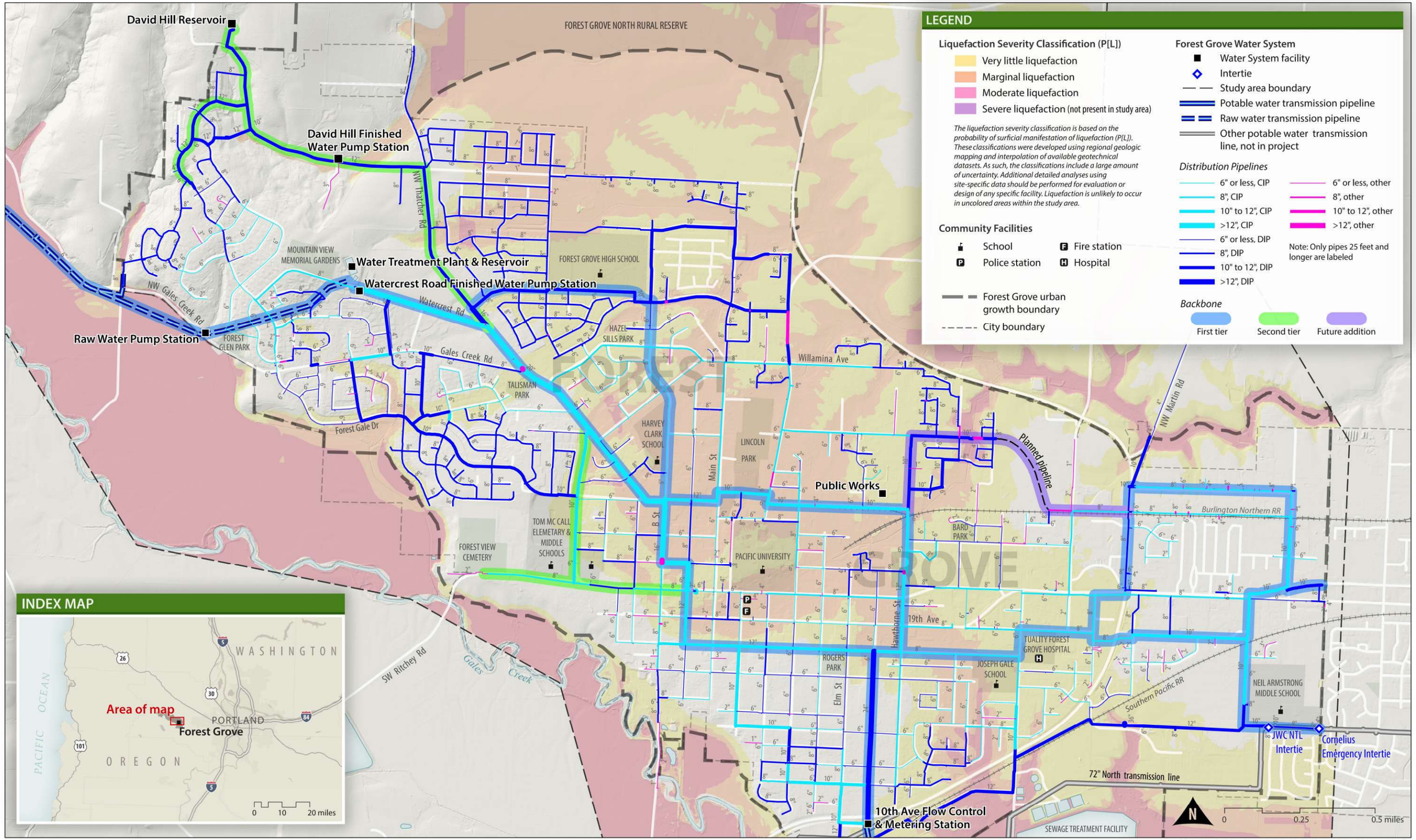
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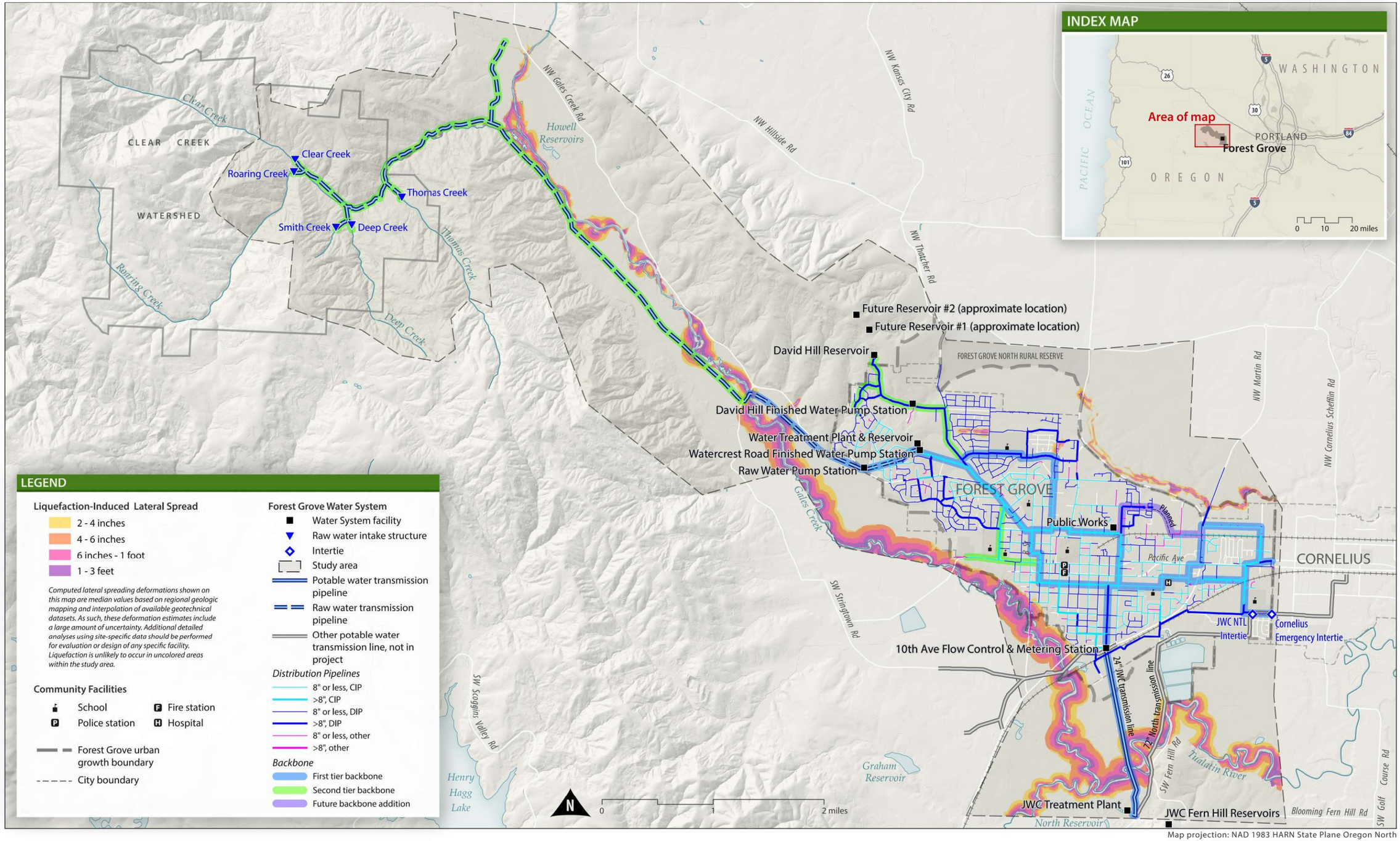
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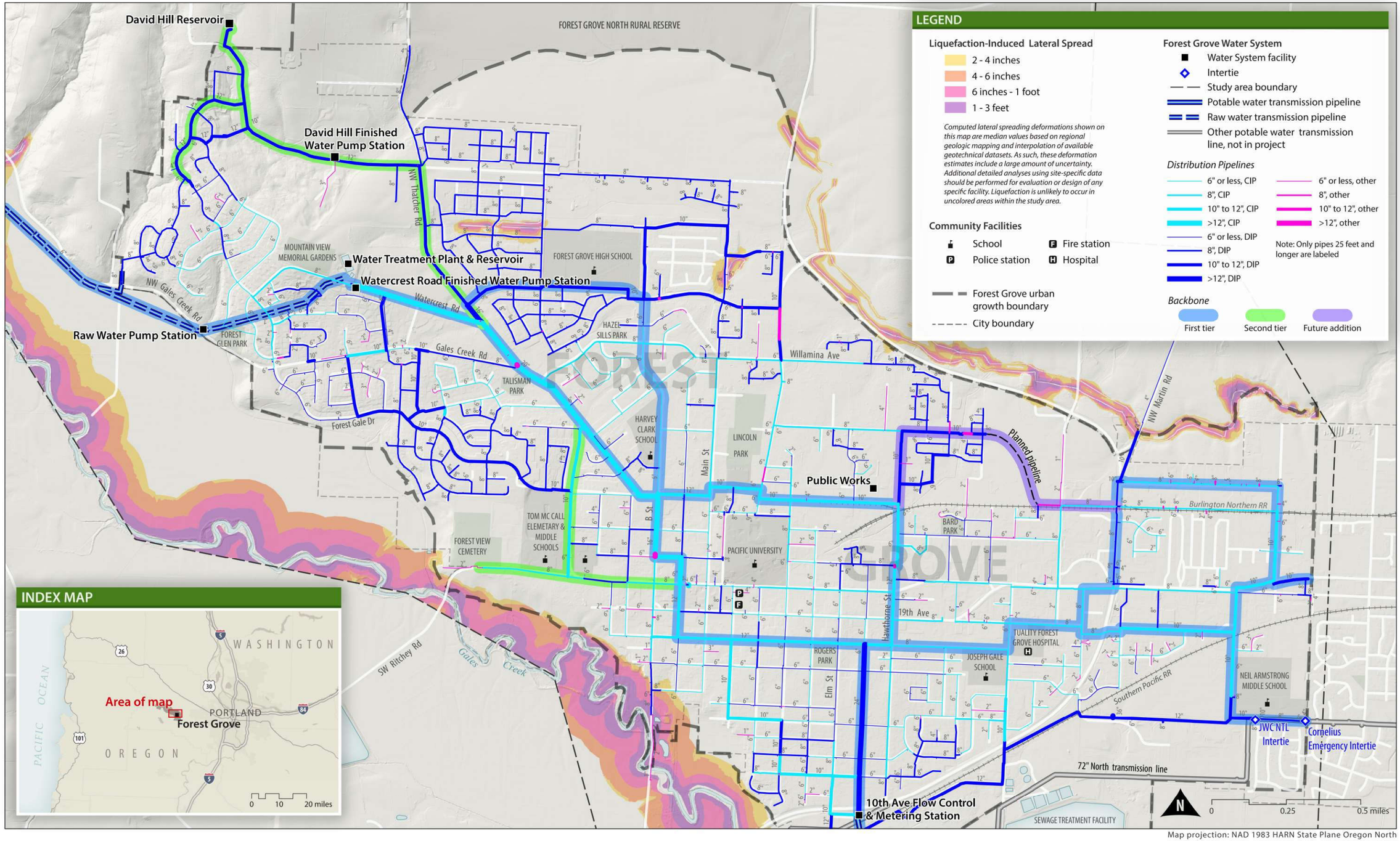
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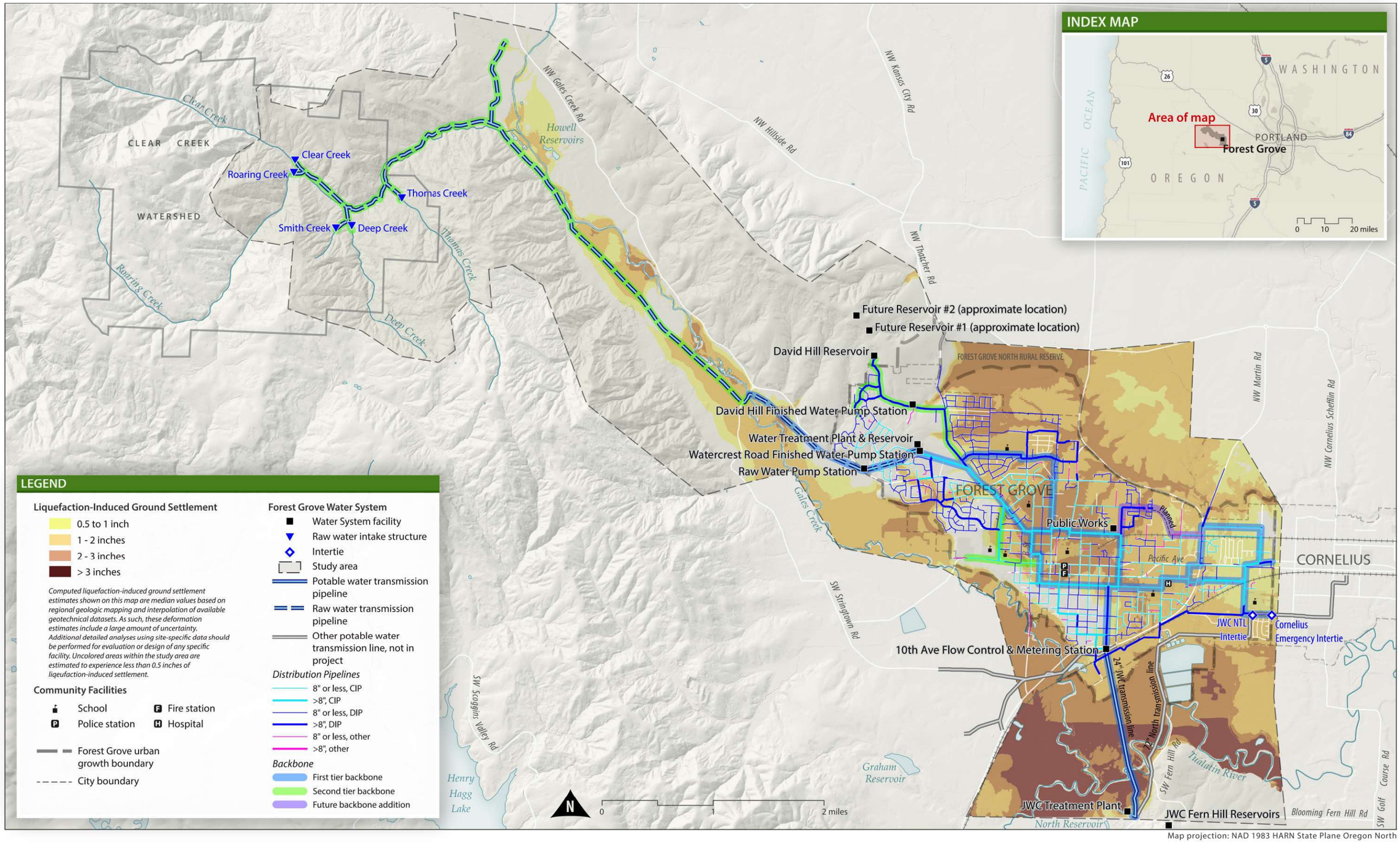
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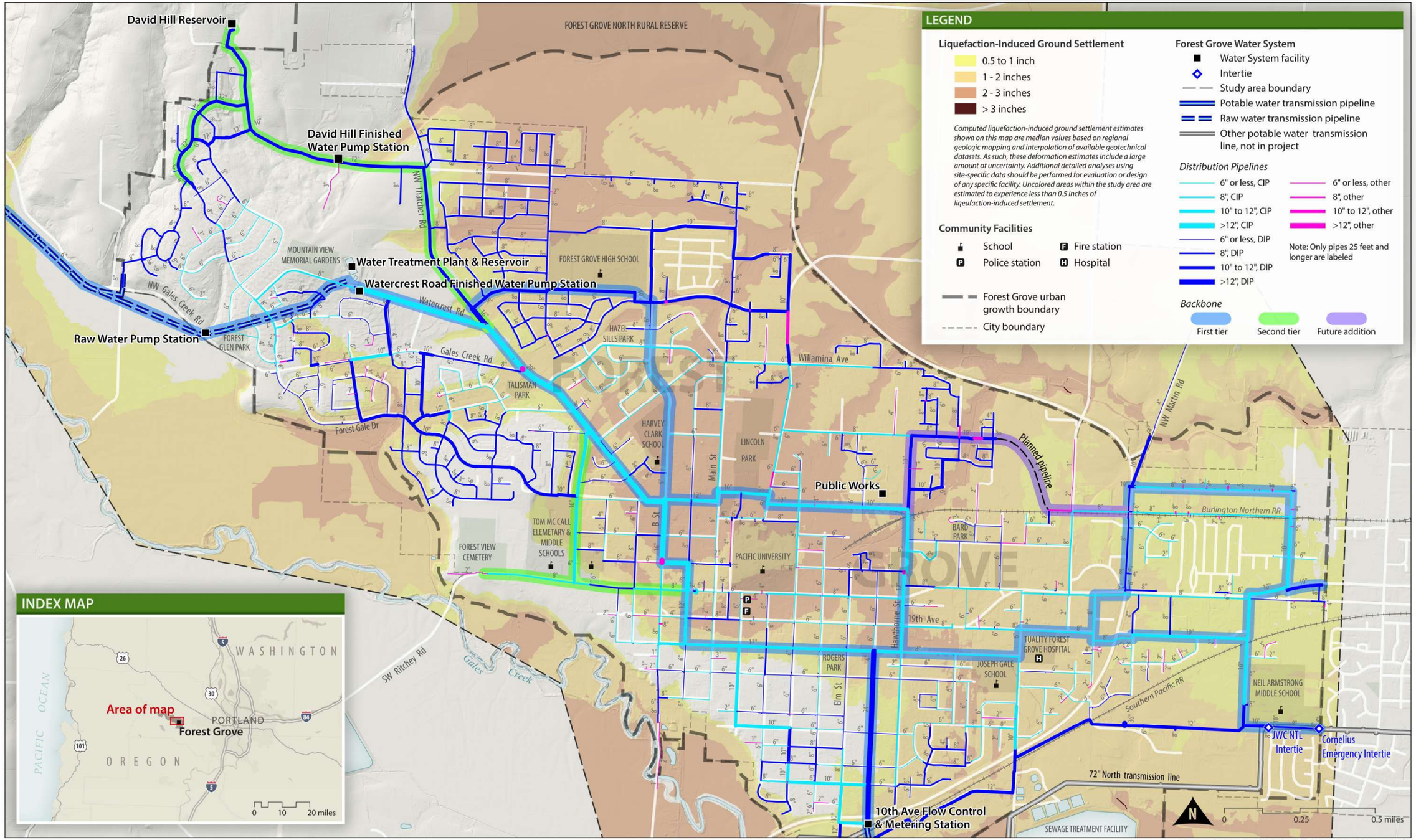
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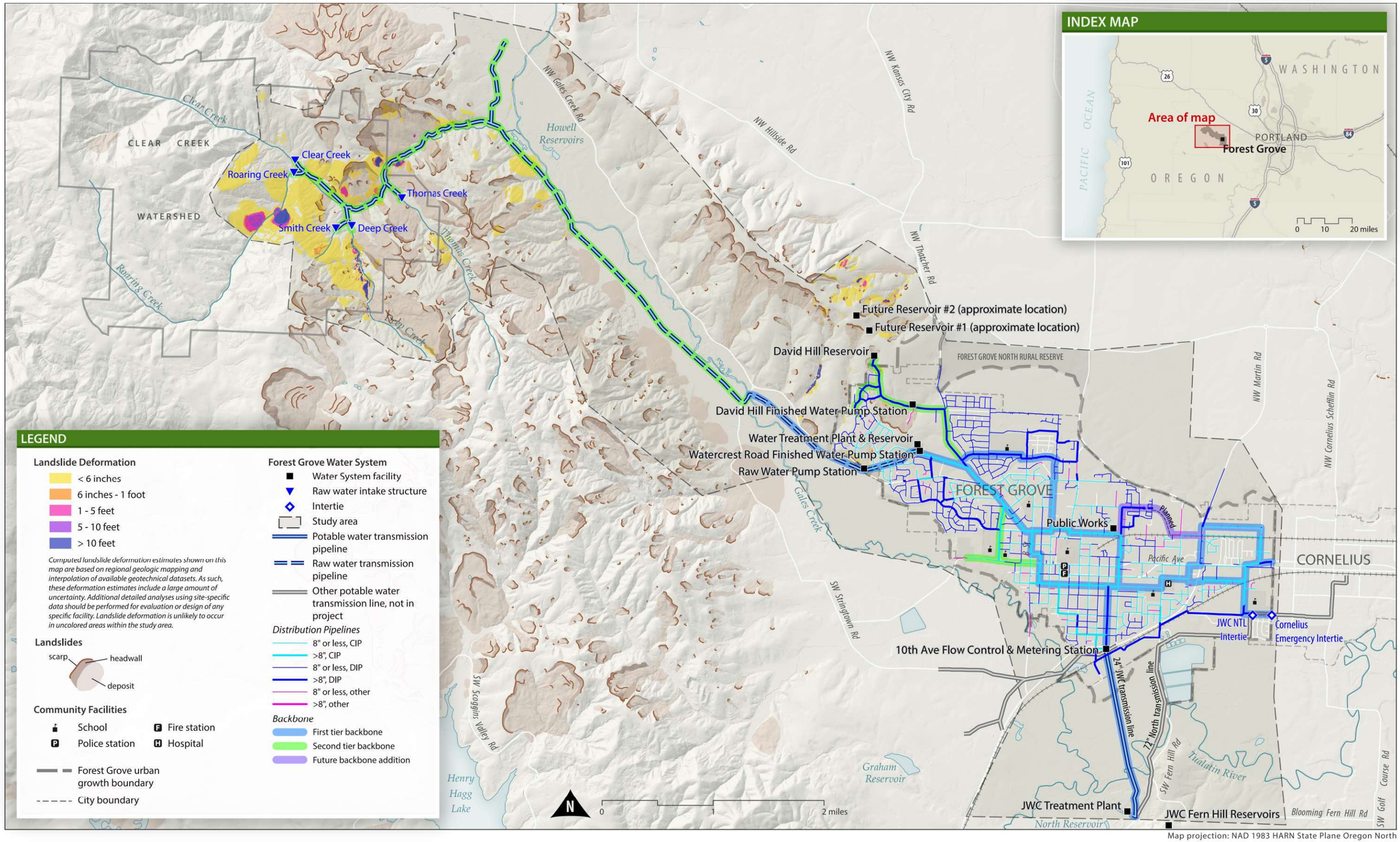
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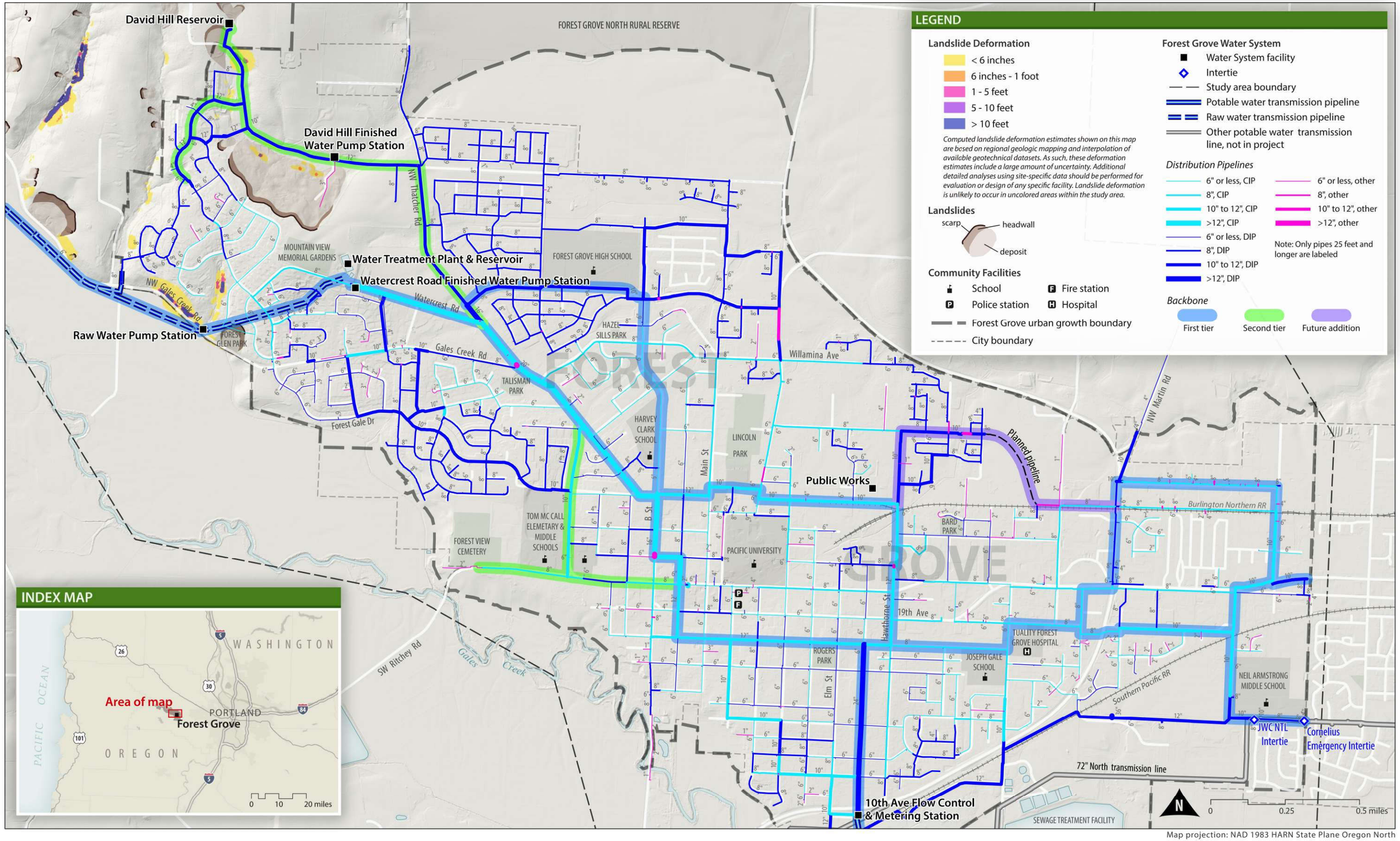
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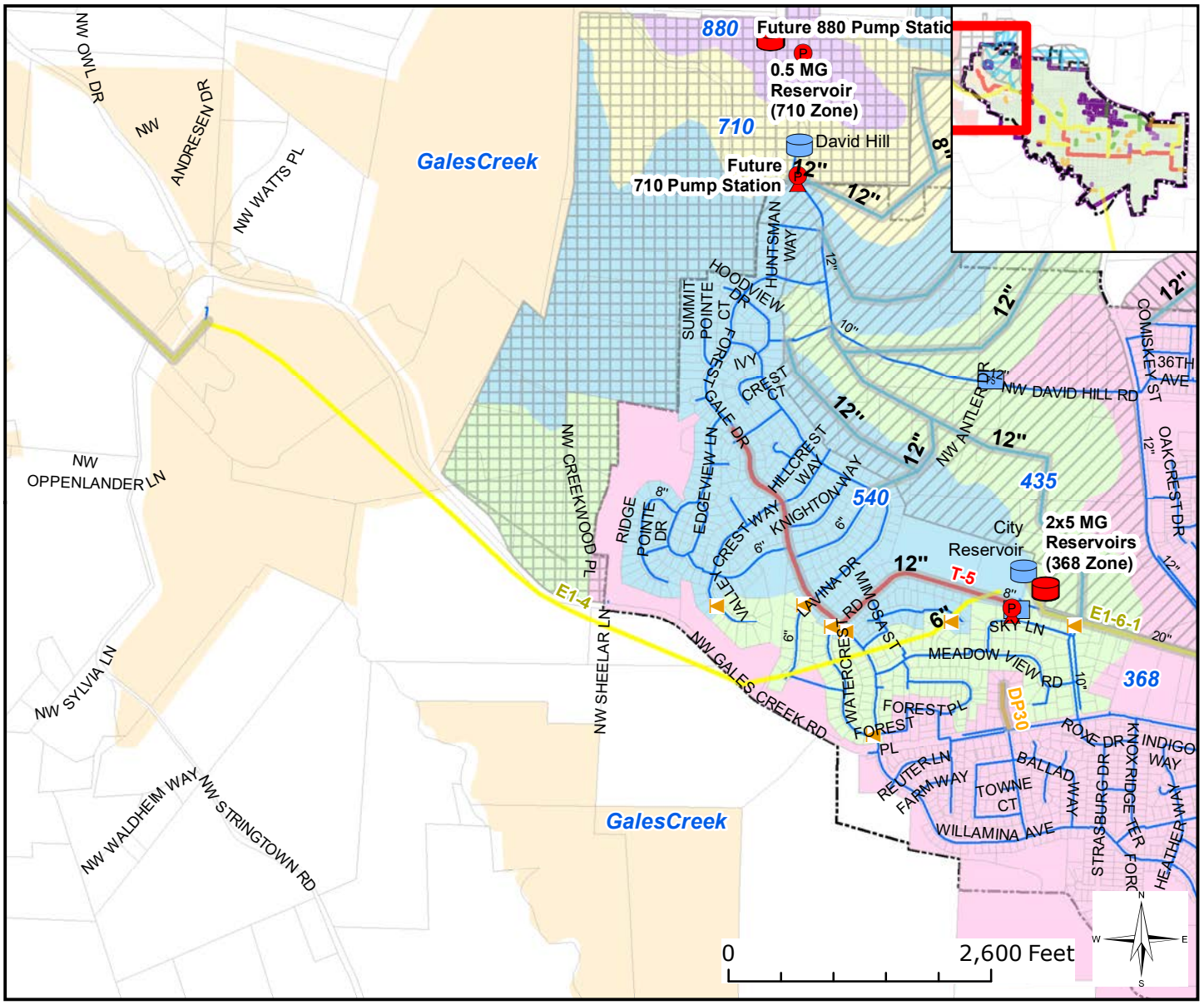


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APPENDIX I
CIP PROJECT SHEETS

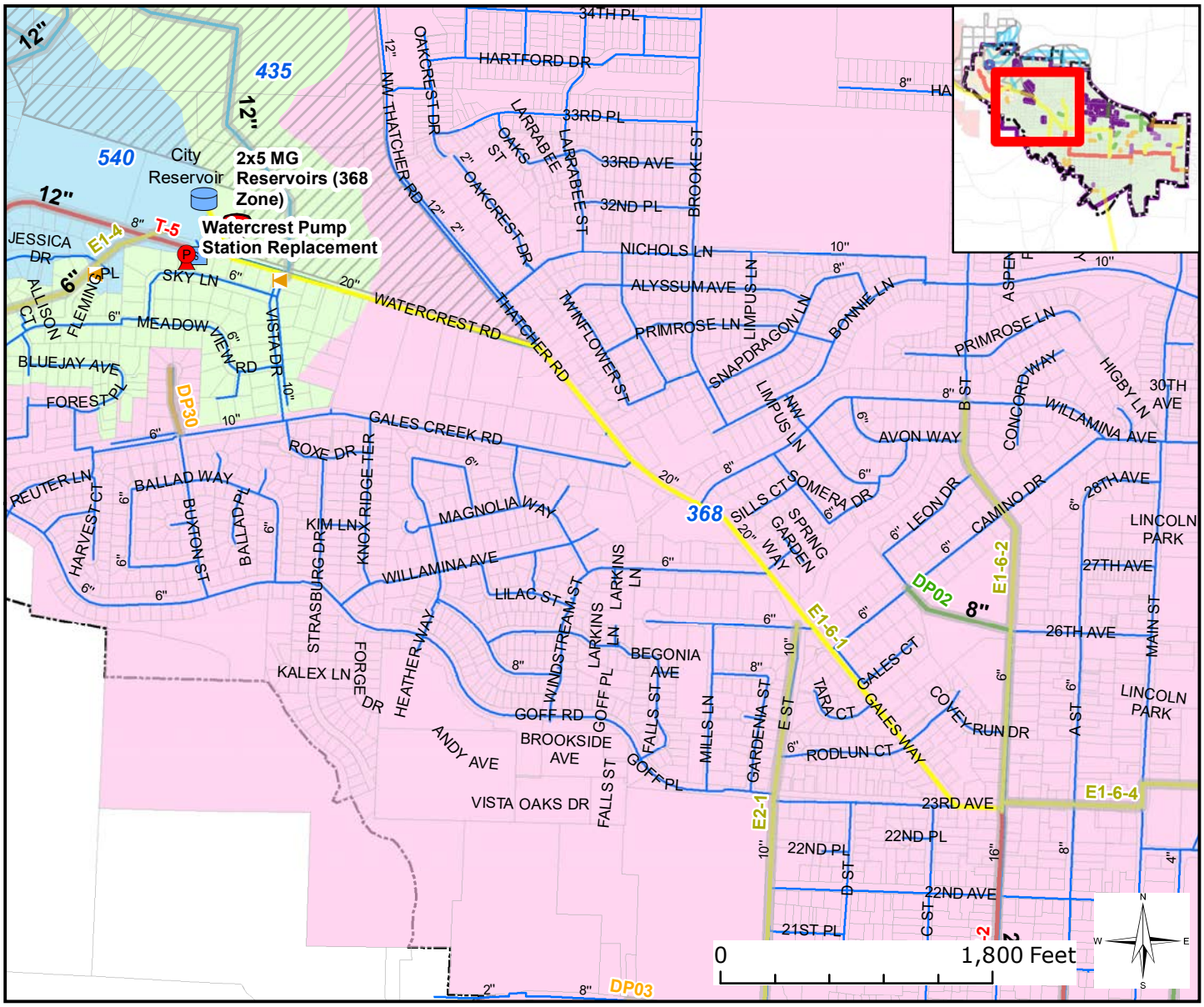


CIP Project E1-4

Project Type: Seismic Resiliency
Project Description: Seismic upgrades to Tier 1 RWTM from Stringtown Bridge to City WTP
Project Need: Improve seismic resiliency
Expected Timeframe: 0-5 Years
Priority: Medium
Project Cost: $3,940,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- Proposed Pump Station
- Proposed Reservoir
- SRP Improvements
- Future Development w/in UGB
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368
- 435
- 540
- 710, Future
- 880, Future
- Gales Creek
- David Hill URA

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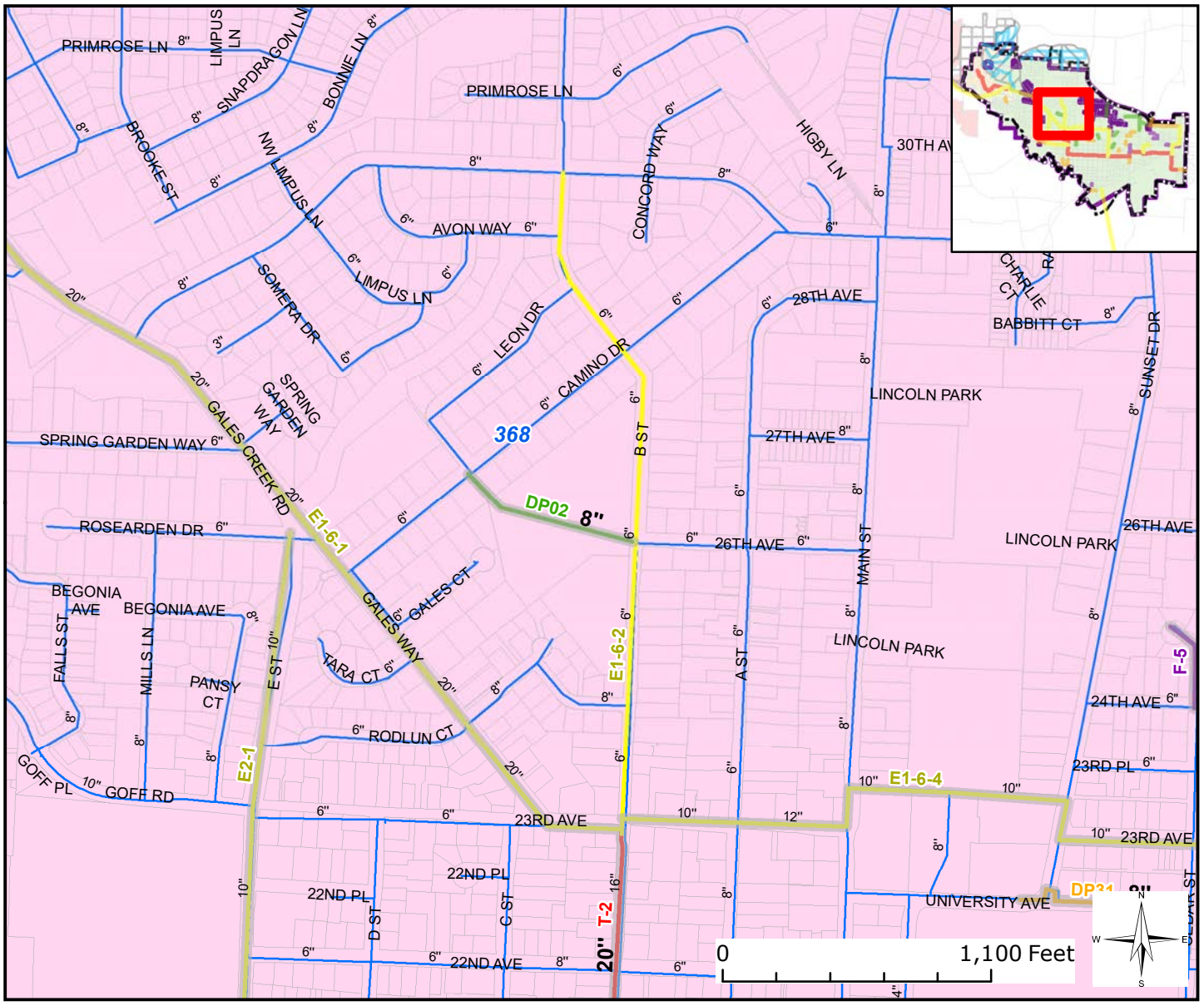


CIP Project E1-6-1

Project Type: Seismic Resiliency
Project Description: Seismic upgrades of 20" cast iron transmission from City WTP to B St, along Watercrest Rd, Thatcher Rd, Gales Ck Rd, and Gales Way
Project Need: Improve seismic resiliency
Expected Timeframe: 0-5 Years
Priority: High
Project Cost: $5,040,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- Proposed Pump Station
- Proposed Reservoir
- SRP Improvements
- Future Development w/in UGB
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368
- 435
- 540
- David Hill UGB

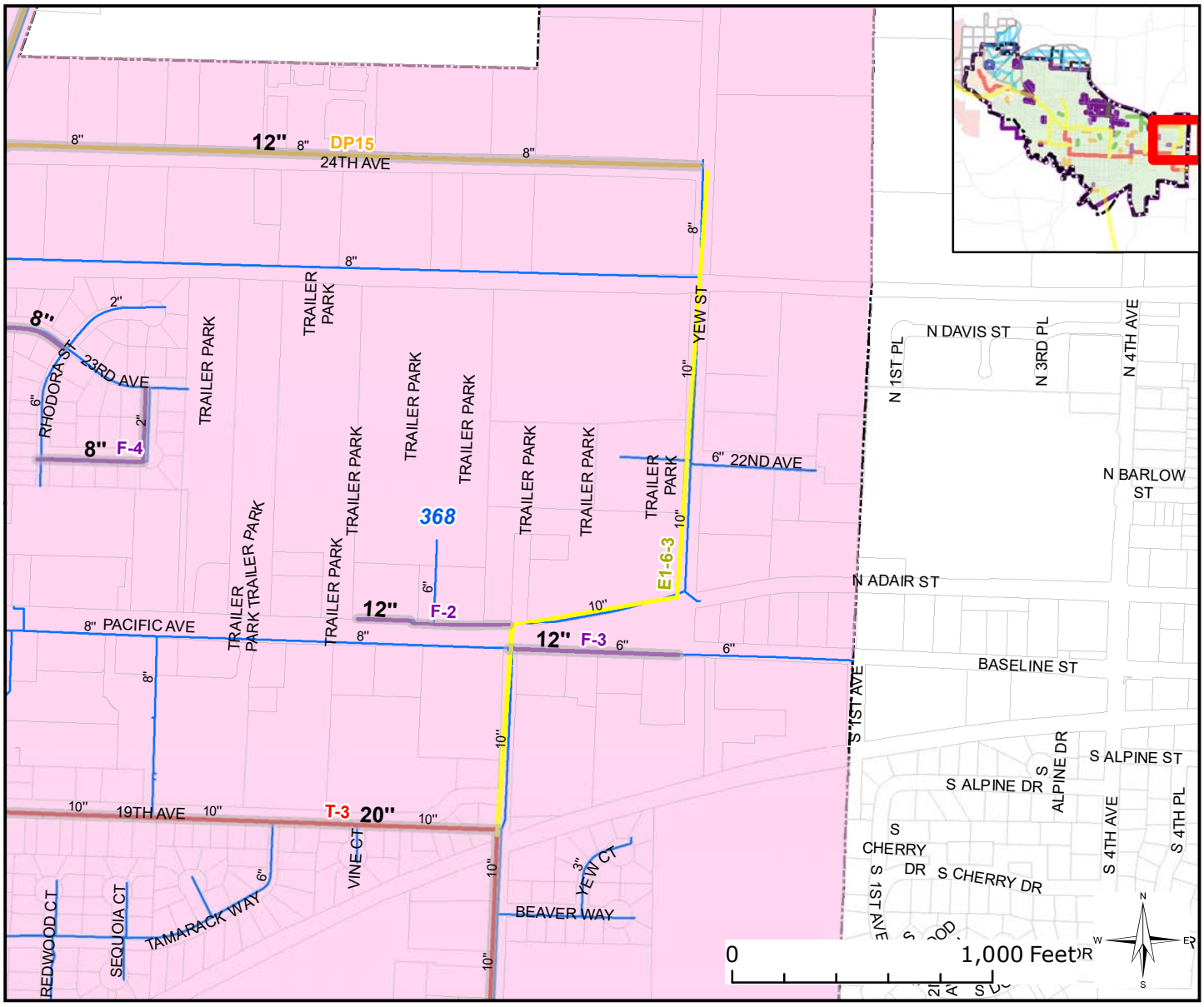
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CIP Project E1-6-2

Project Type: Seismic Resiliency
Project Description: Seismic upgrades of 6" cast iron and upsizing to at least 8" along B St to serve Forest Grove High School
Project Need: Improve seismic resiliency
Expected Timeframe: 0-5 Years
Priority: Medium
Project Cost: $820,000
Project Phasing: N/A

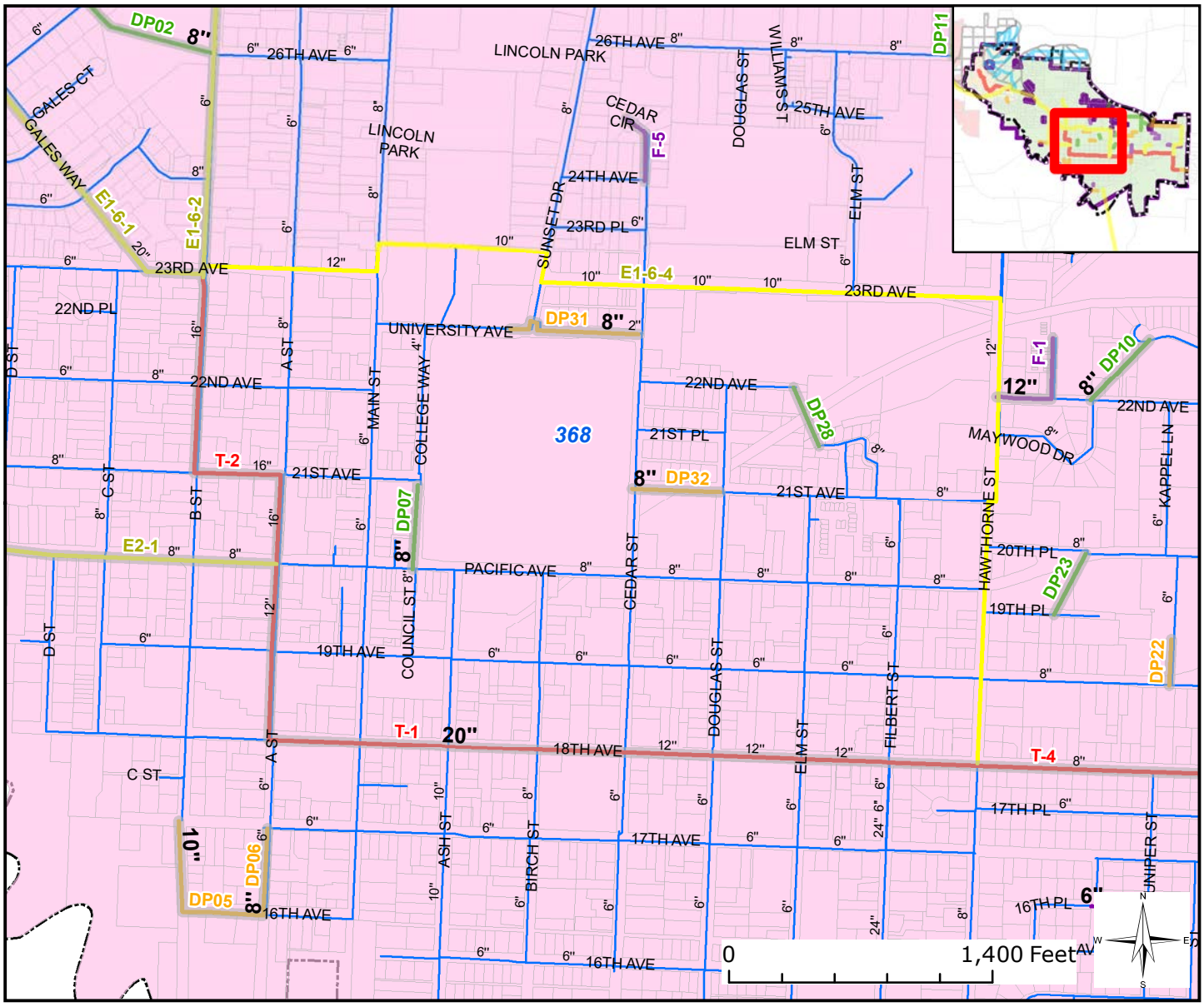
- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368



CIP Project E1-6-3

Project Type: Seismic Resiliency
Project Description: Seismic upgrades of 8-10" cast iron along Mountainview Ln and Yew St to loop to industrial center
Project Need: Improve seismic resiliency
Expected Timeframe: 0-5 Years
Priority: Low
Project Cost: $1,340,000
Project Phasing: N/A

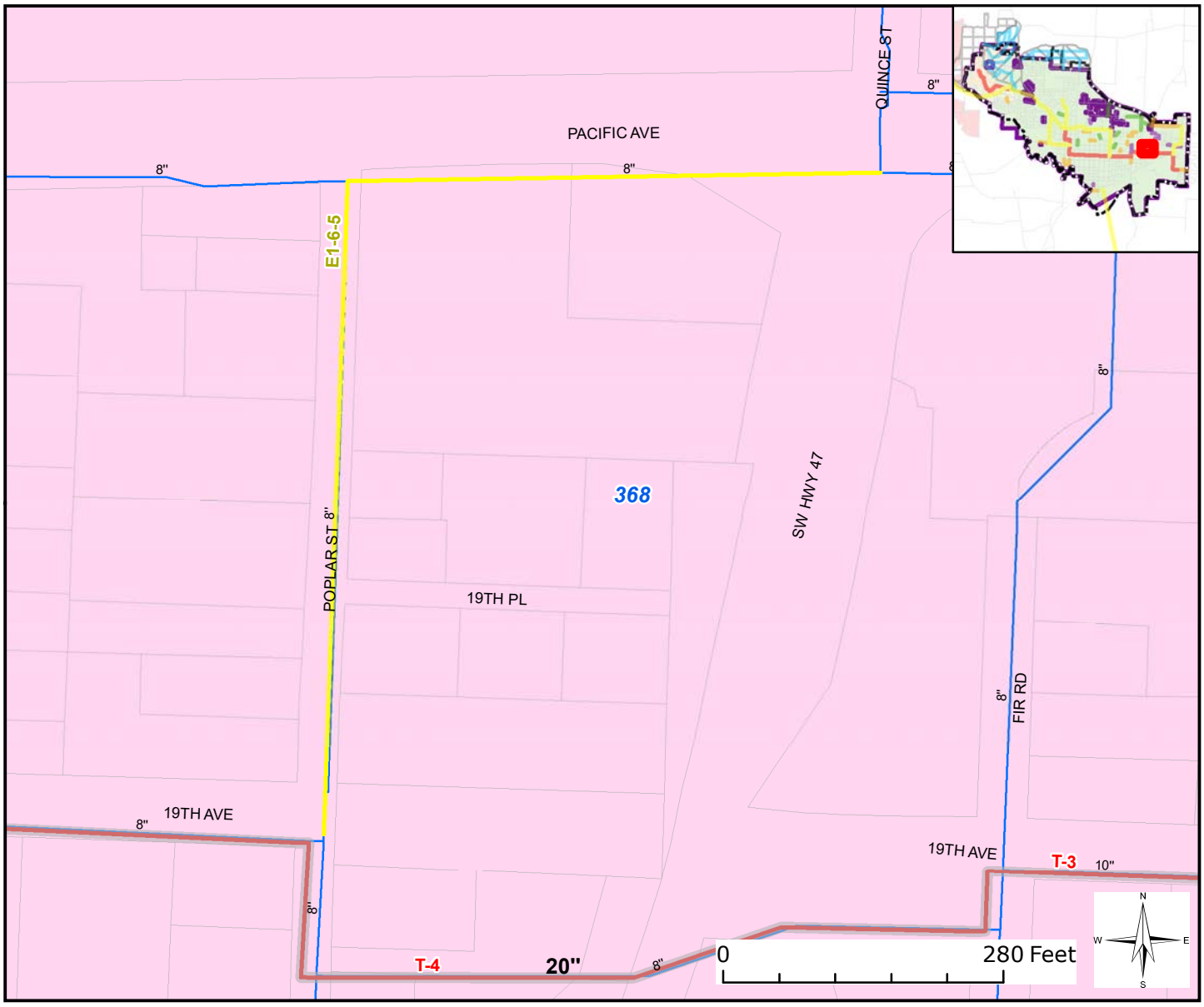
- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368



CIP Project E1-6-4

Project Type: Seismic Resiliency
Project Description: Seismic upgrades of 10-12" cast iron looping north around Pacific University
Project Need: Improve seismic resiliency
Expected Timeframe: 0-5 Years
Priority: Medium
Project Cost: $2,050,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

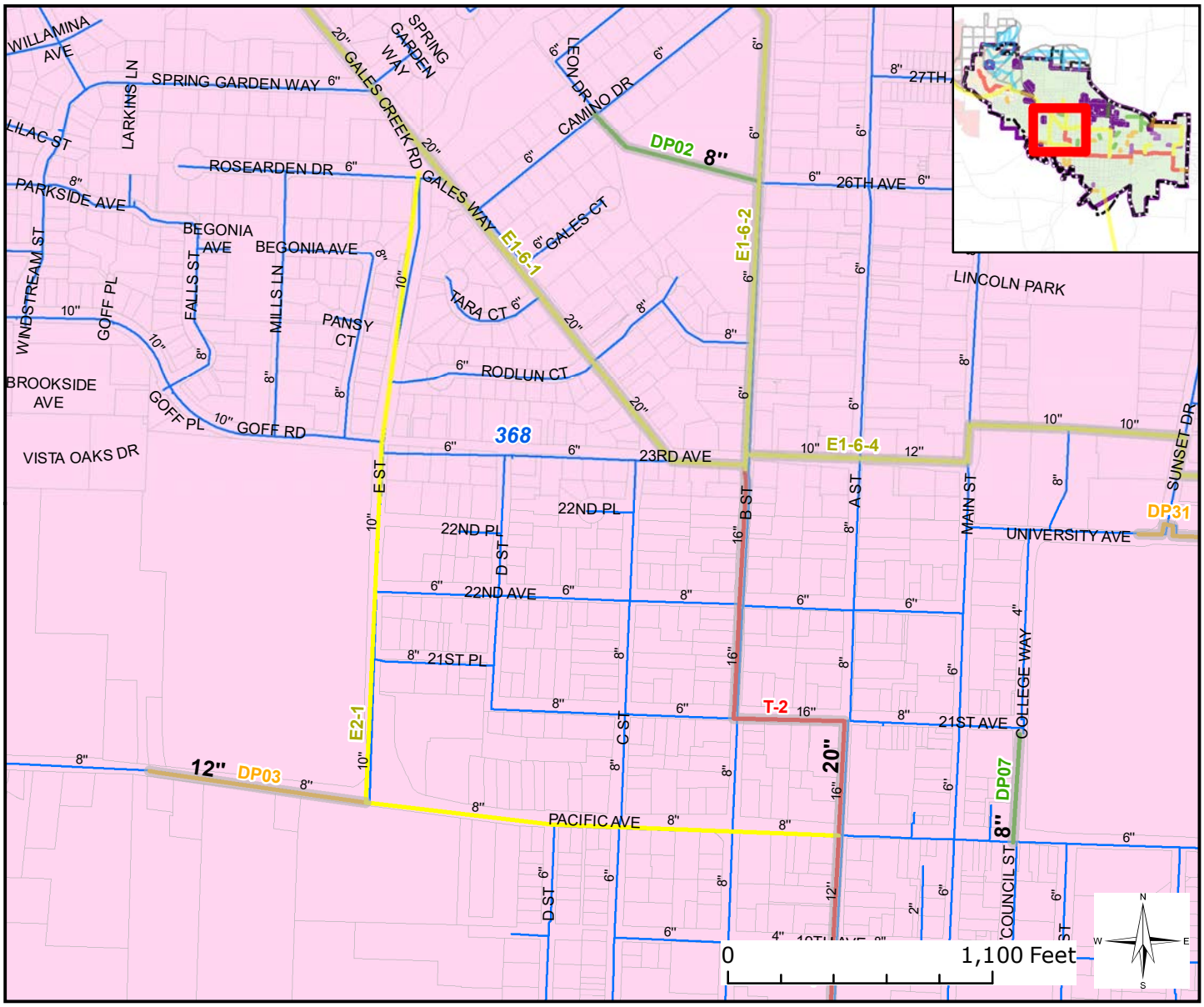


CIP Project E1-6-5

Project Type: Seismic Resiliency
Project Description: Seismic upgrades of 8" cast iron along Poplar St and Pacific Ave to loop to industrial center
Project Need: Improve seismic resiliency
Expected Timeframe: 0-5 Years
Priority: Medium
Project Cost: $430,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- SRP Improvements
- Transmission Improvements
- 368

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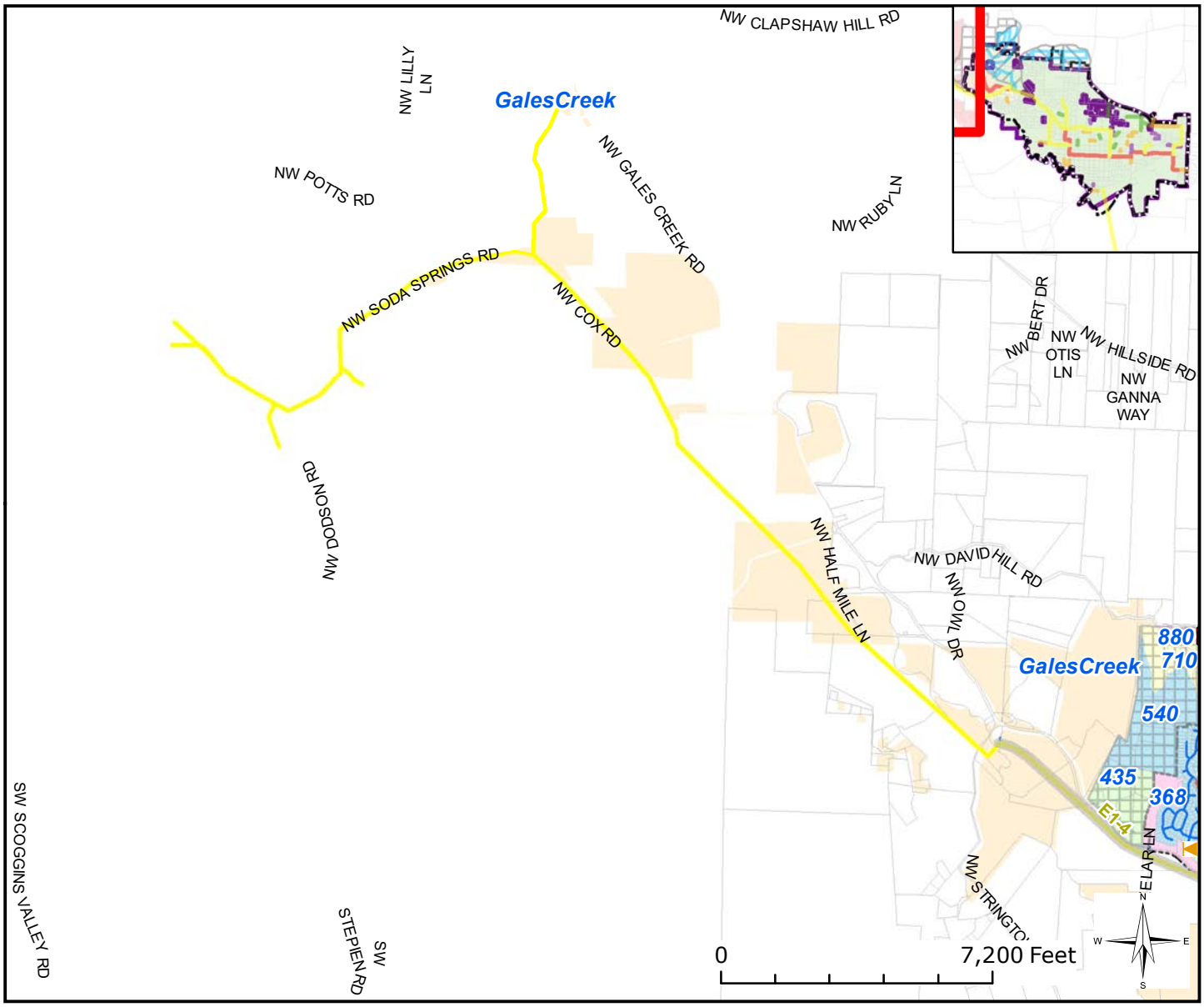


CIP Project E2-1

Project Type: Seismic Resiliency
Project Description: Seismic upgrades to Tier 2 backbone 8-10" cast iron to loop to Tom McCall Elementary and Middle Schools
Project Need: Improve seismic resiliency
Expected Timeframe: 10-20 Years
Priority: Low
Project Cost: $1,500,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- SRP Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

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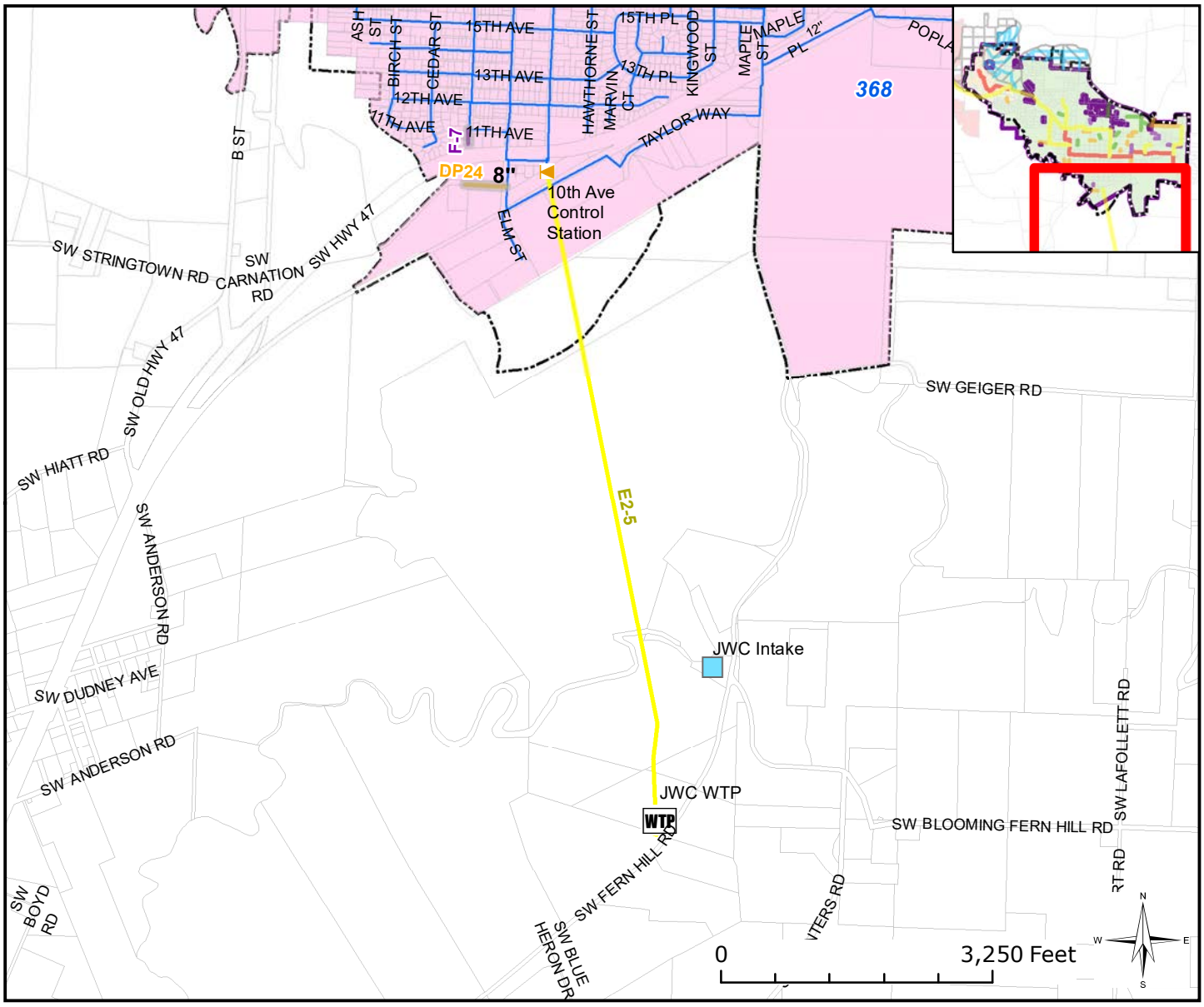


CIP Project E2-3

Project Type: Seismic Resiliency
Project Description: Seismic upgrades to Tier 2 RWTM from intakes to Stringtown Bridge
Project Need: Improve seismic resiliency
Expected Timeframe: 20+ Years
Priority: Low
Project Cost: $17,040,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- Proposed Reservoir
- SRP Improvements
- Transmission Improvements
- 368
- 435
- 540
- 710, Future
- 880, Future
- Gales Creek
- David Hill URA

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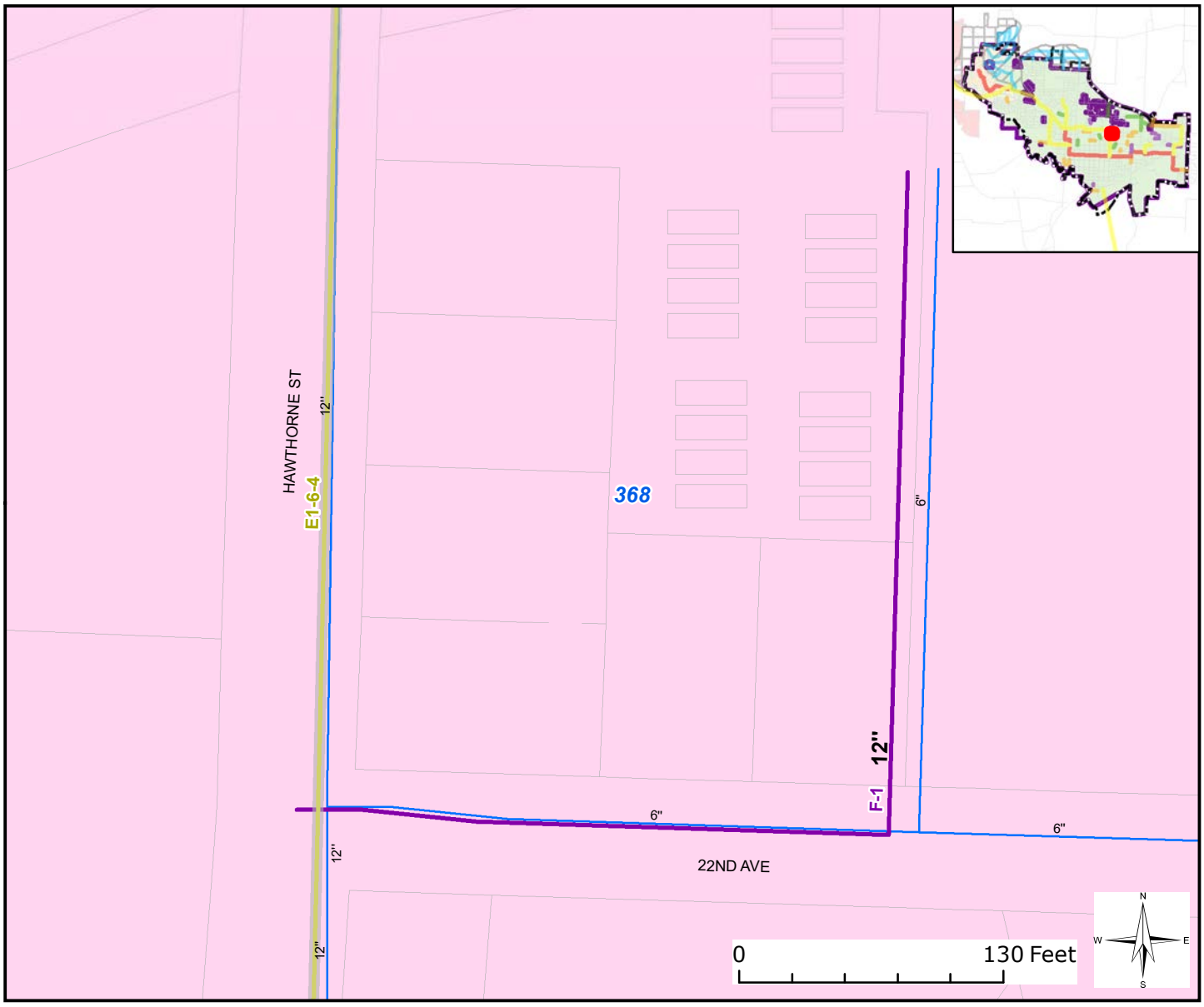


CIP Project E2-5

Project Type: Transmission and Seismic Resiliency
Project Description: Seismic upgrades to JWC Supply and increased capacity through either upsizing or leasing from Hillsboro
Project Need: Improve seismic resiliency and provide additional JWC transmission capacity
Expected Timeframe: 0-5 Years
Priority: High
Project Cost: $5,940,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

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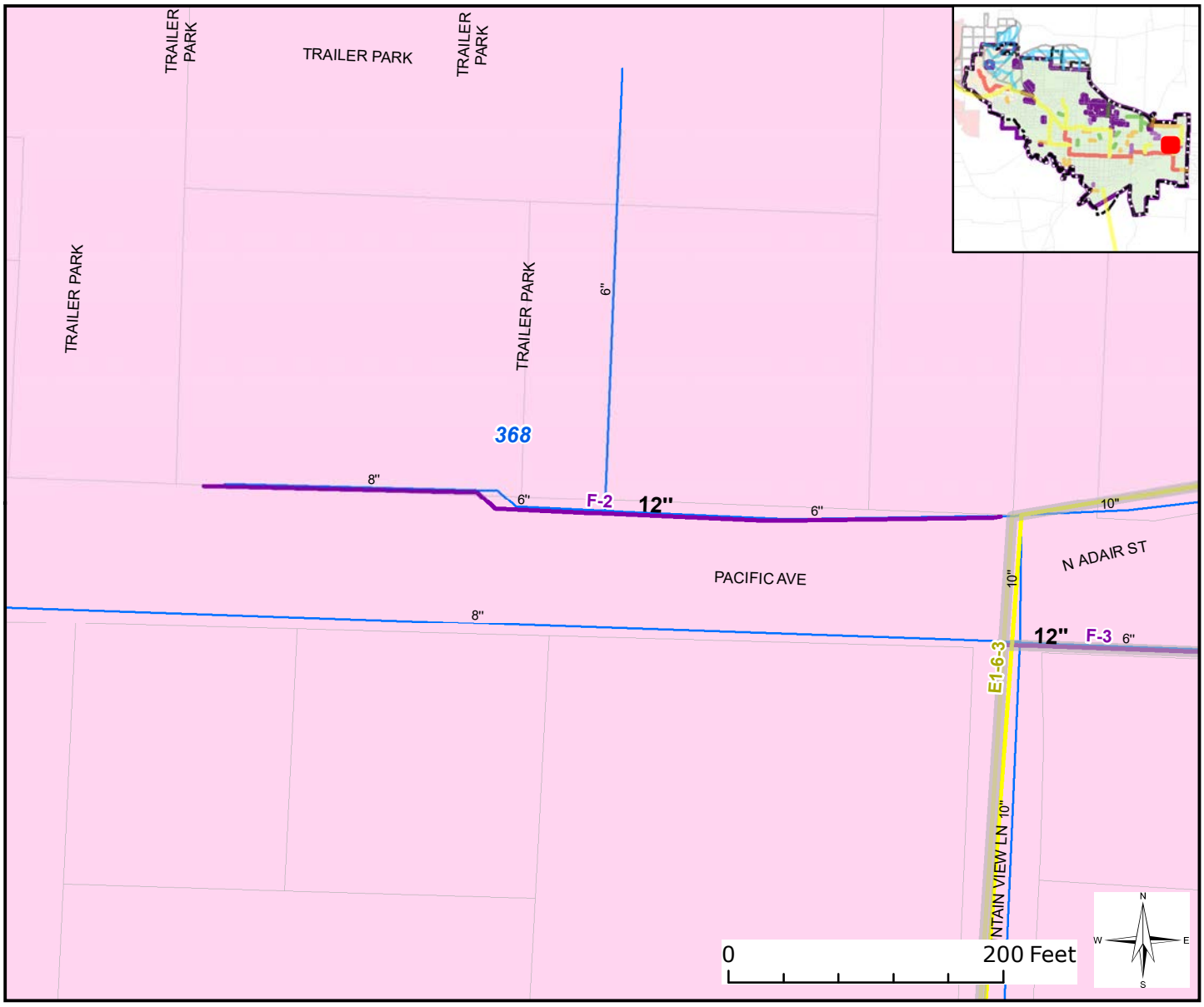


CIP Project F-1

Project Type: Fire Flow Improvement
Project Description: Multifamily Residential - 22nd Ave - Garden Grove Apartments - upsize to 12"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $260,000
Project Phasing: N/A

PS PumpStation
PRV
Tank
SRP Improvements
Fire Flow Improvements
368

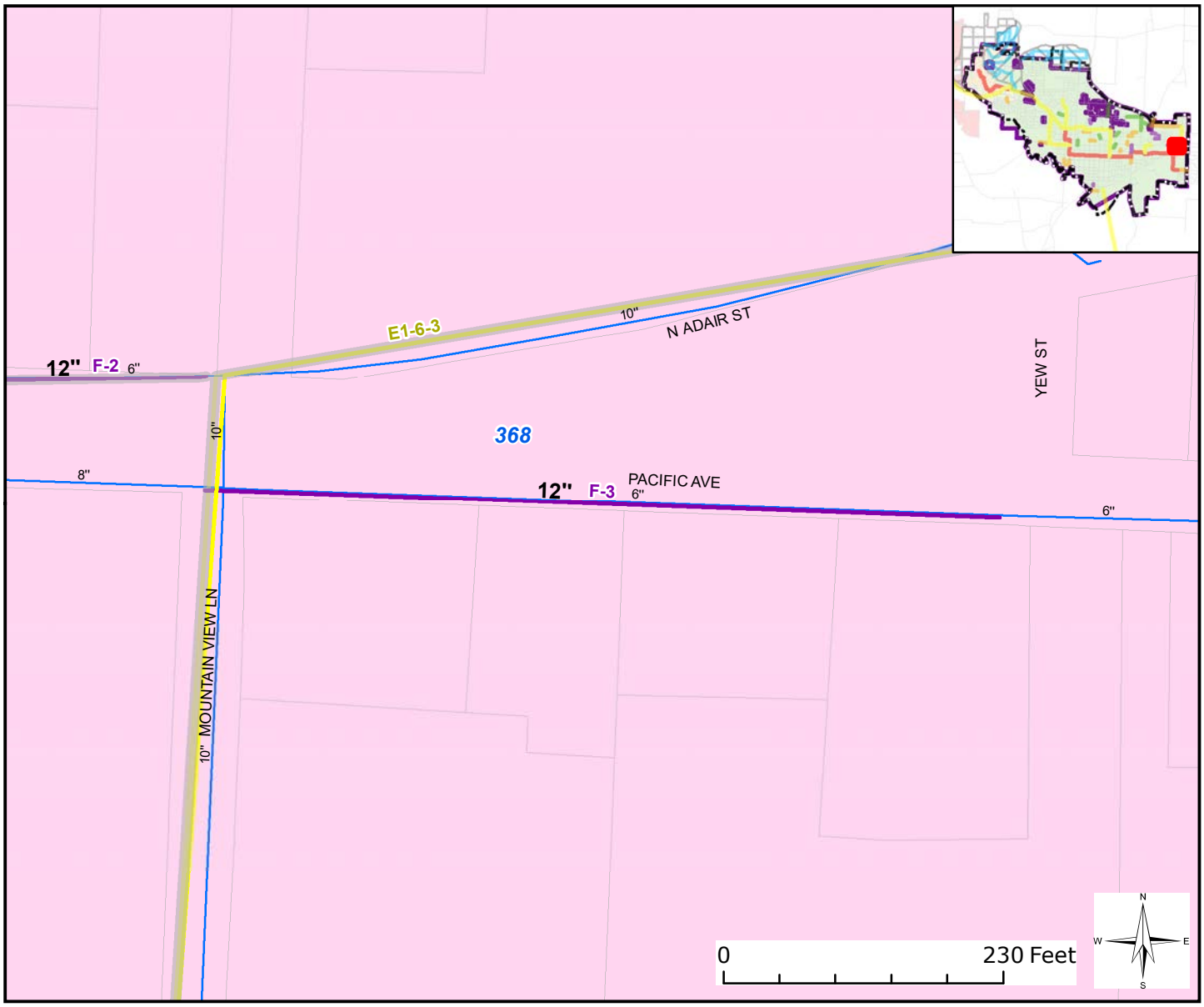
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CIP Project F-2

Project Type: Fire Flow Improvement
Project Description: Commercial - Pacific Ave - Best Western - upsize to 12"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $260,000
Project Phasing: N/A

PS PumpStation
PRV
Tank
SRP Improvements
Fire Flow Improvements
368

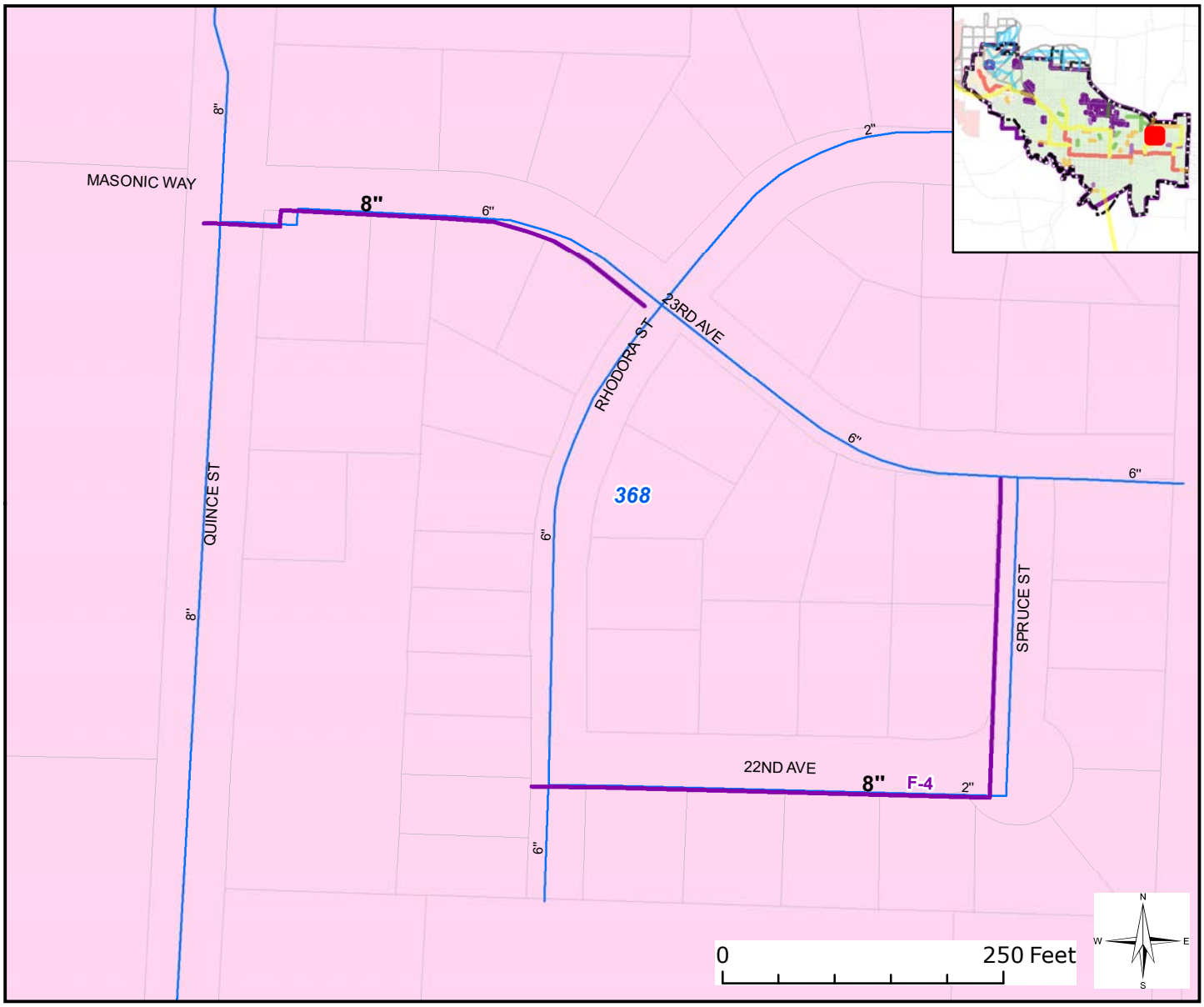


CIP Project F-3

Project Type: Fire Flow Improvement
Project Description: Commercial - Pacific Ave - Mountain View Ln to Yew St - upsize to 12"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $520,000
Project Phasing: N/A

PS PumpStation
PRV
Tank
SRP Improvements
Fire Flow Improvements
368

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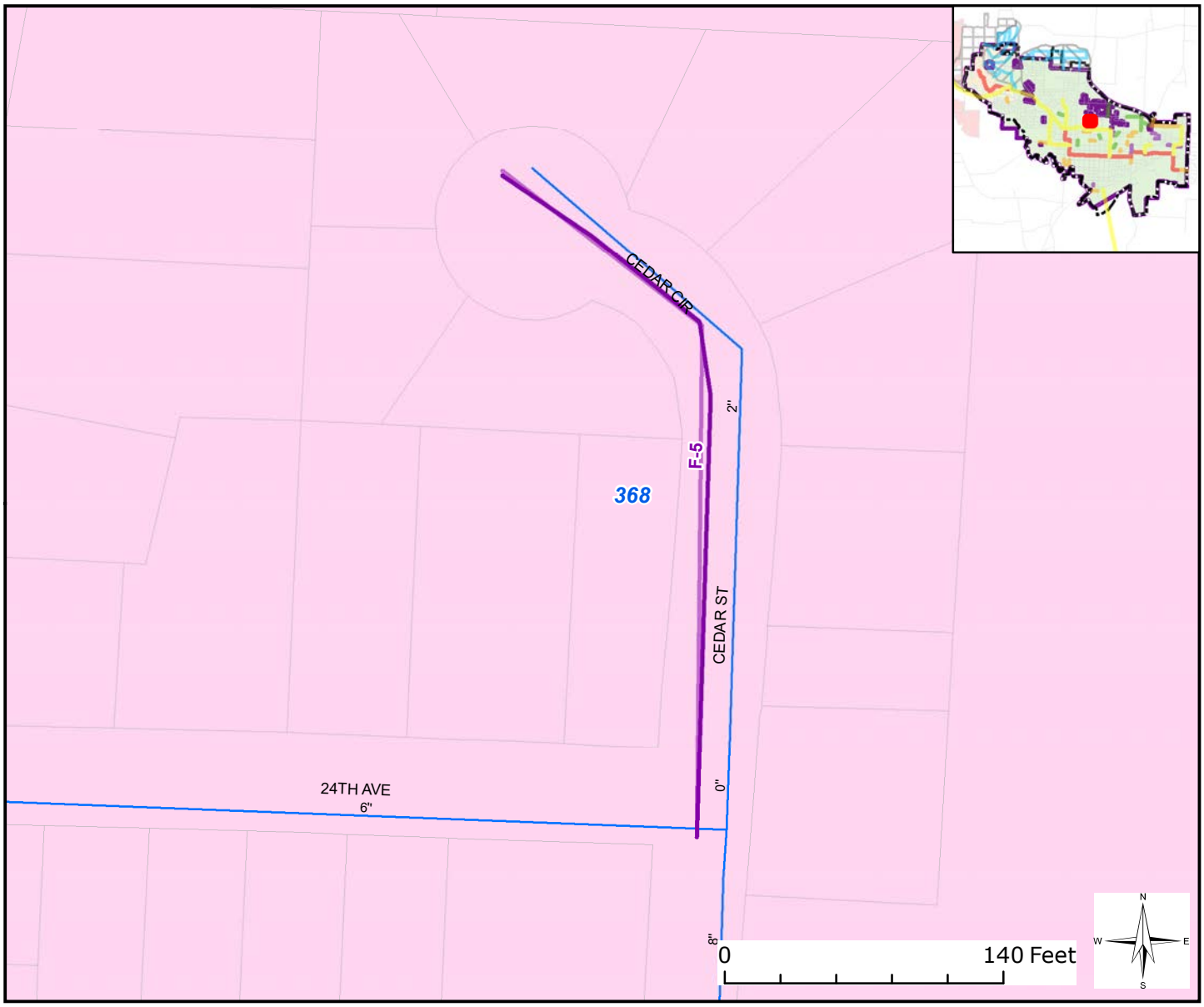


CIP Project F-4

Project Type: Fire Flow Improvement
Project Description: Residential – 23rd Ave - upsize to 8"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $350,000
Project Phasing: N/A

PumpStation
PRV
Tank
Fire Flow Improvements
368

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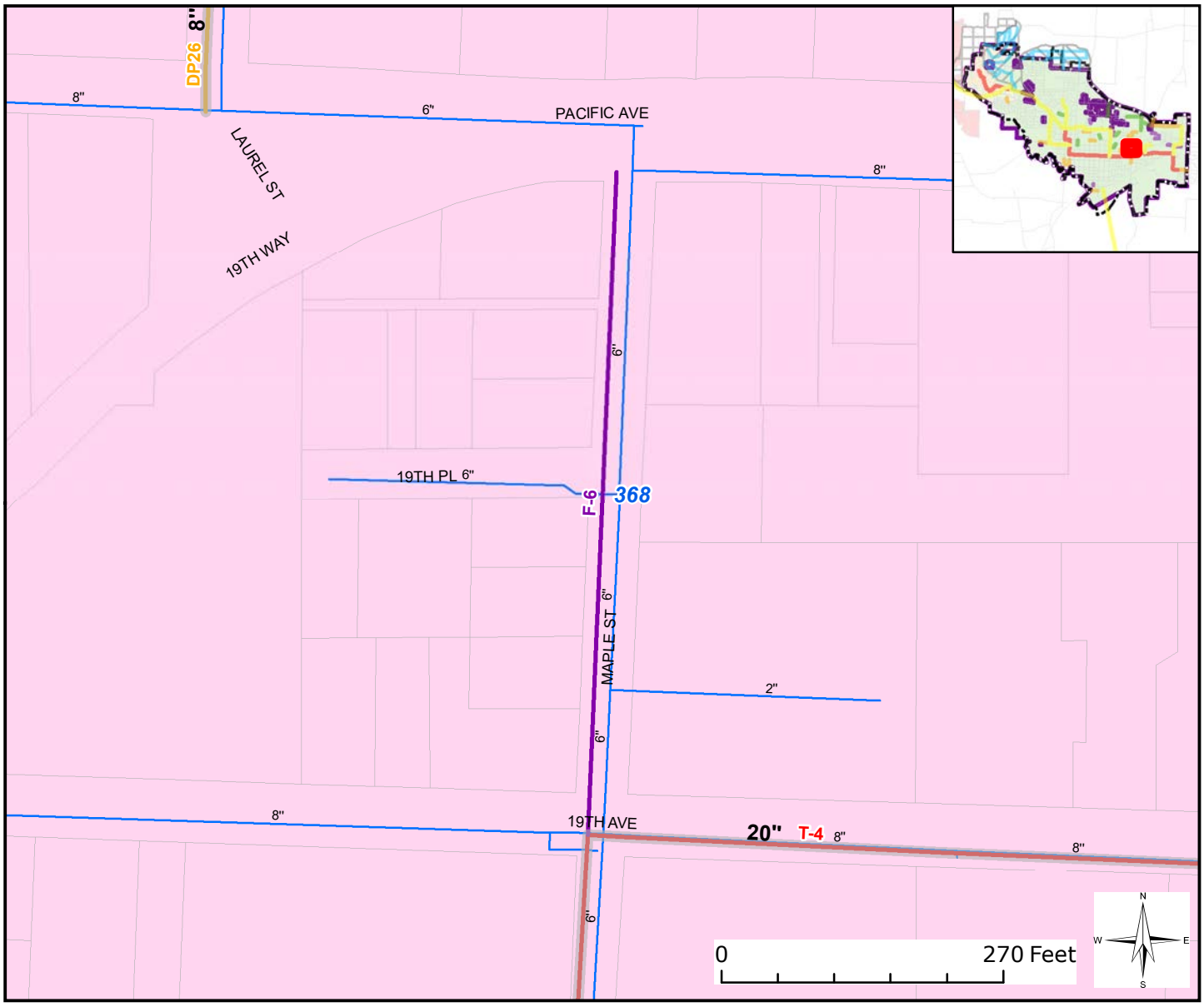


CIP Project F-5

Project Type: Fire Flow Improvement
Project Description: Residential - Cedar St - upsize to 6"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $90,000
Project Phasing: N/A

PumpStation
PRV
Tank
Fire Flow Improvements
368

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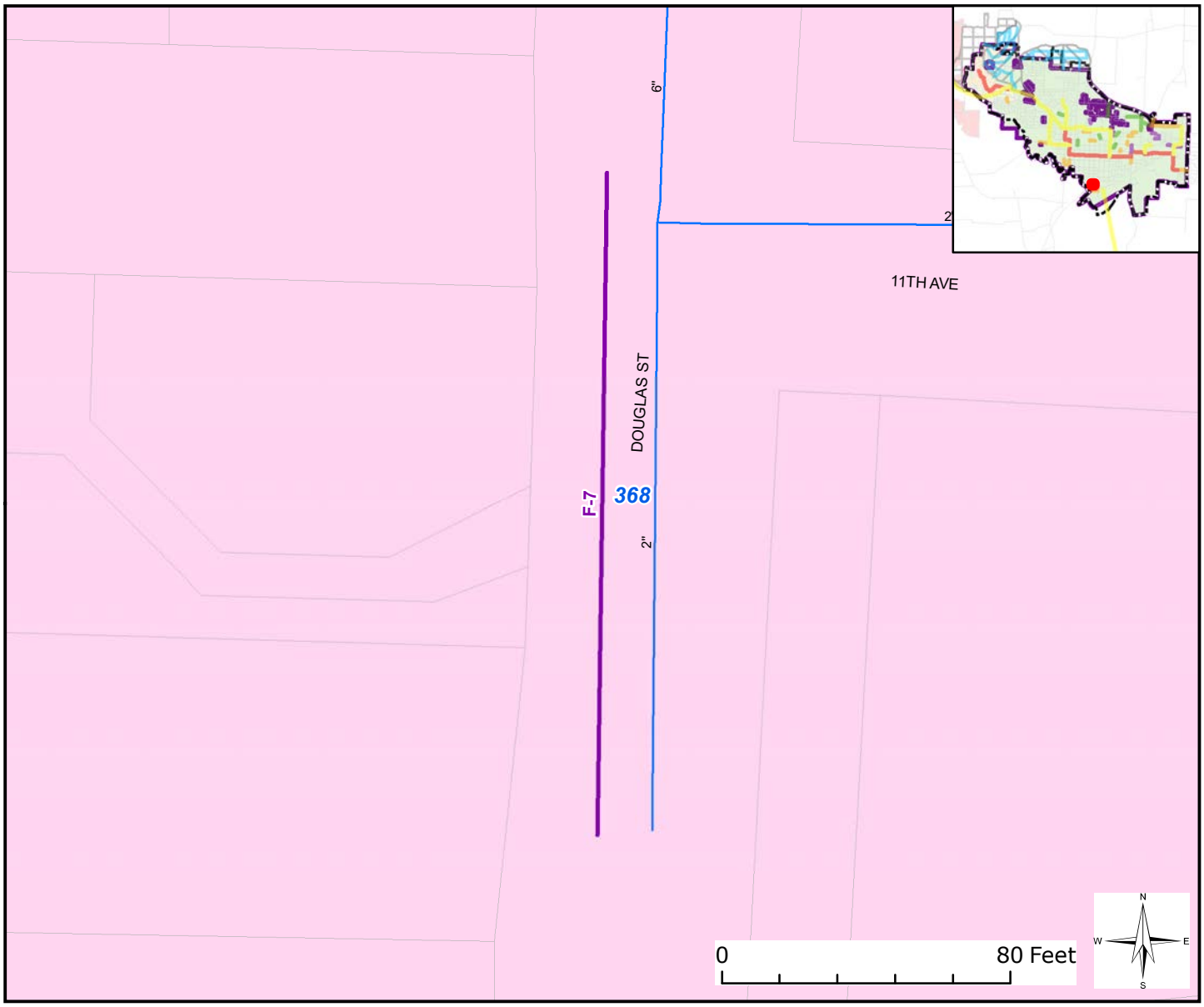


CIP Project F-6

Project Type: Fire Flow Improvement
Project Description: Industrial - Maple Street from 18th to 19th - upsize to 8"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $250,000
Project Phasing: N/A

- PumpStation
- PRV
- Tank
- Fire Flow Improvements
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

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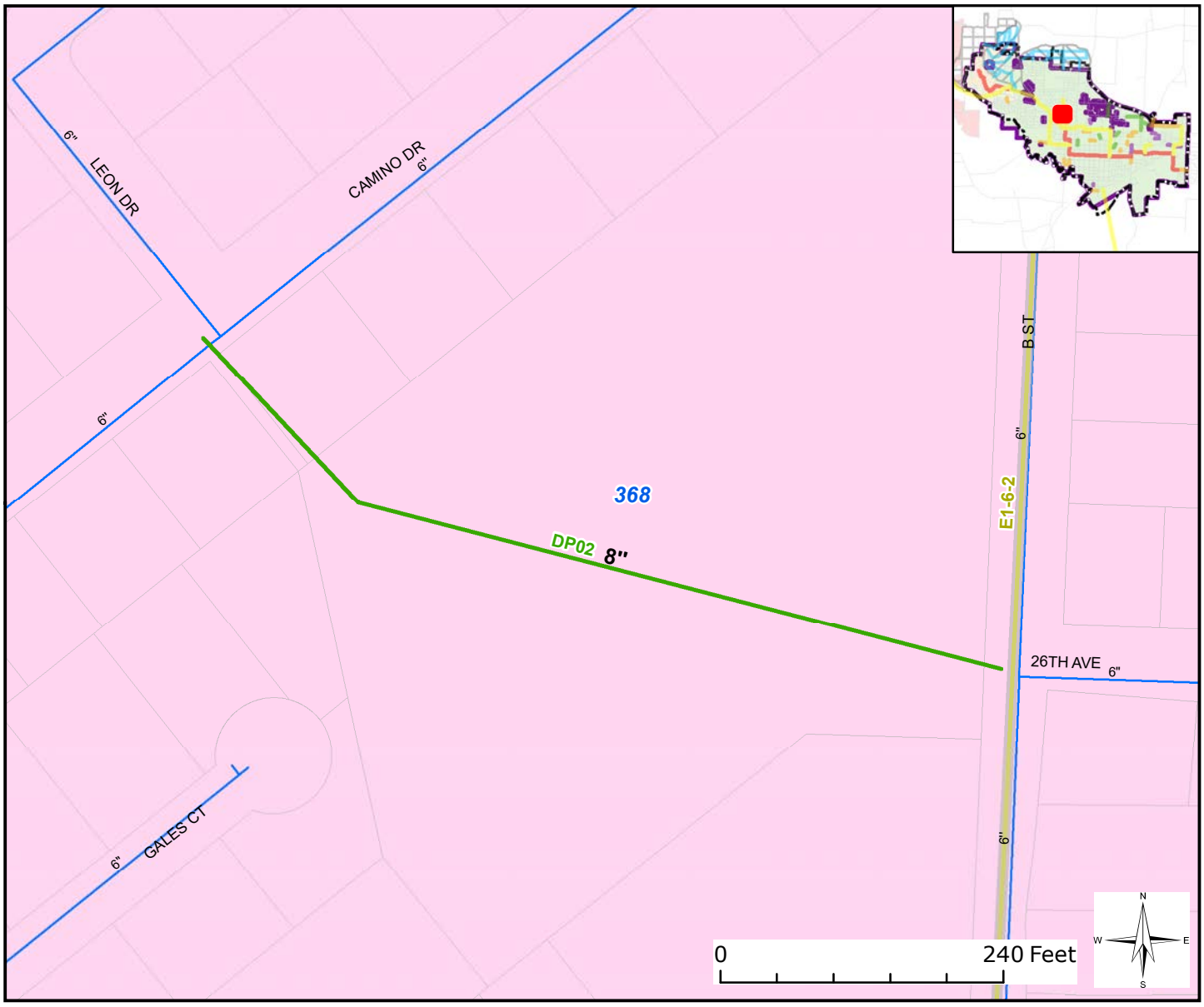


CIP Project F-7

Project Type: Fire Flow Improvement
Project Description: Residential - Douglas St - upsize to 6"
Project Need: Improve fire flow availability
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $40,000
Project Phasing: N/A

PS PumpStation
PRV
Tank
Fire Flow Improvements
368

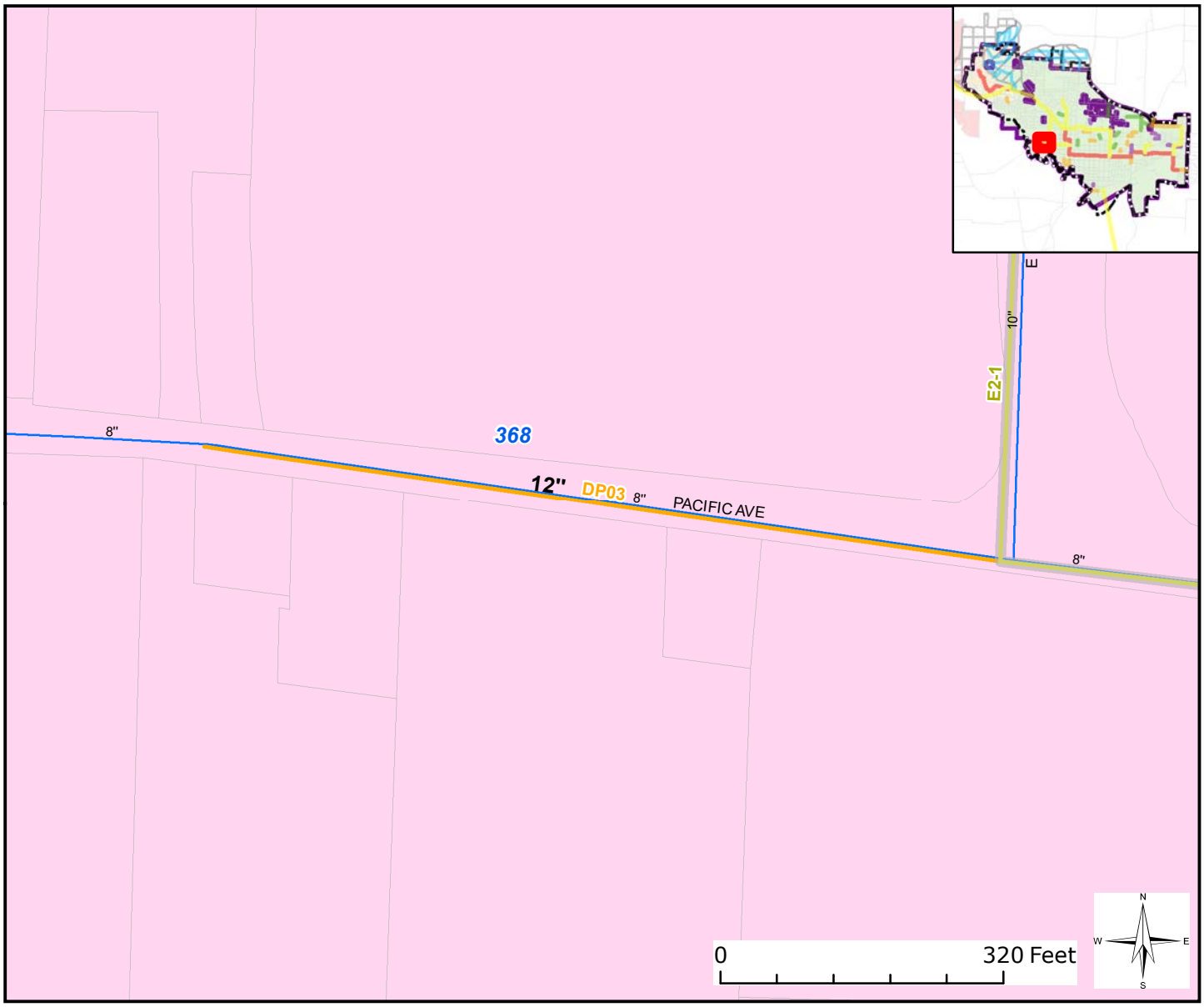
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CIP Project HDR_DP02

Project Type: HDR New Pipes
Project Description: Harvey Clarke Elementary
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $220,000
Project Phasing: As development opportunities arise

- PumpStation
- PRV
- Tank
- SRP Improvements
- Prior WMP Improvements, Upsize Existing
- 368

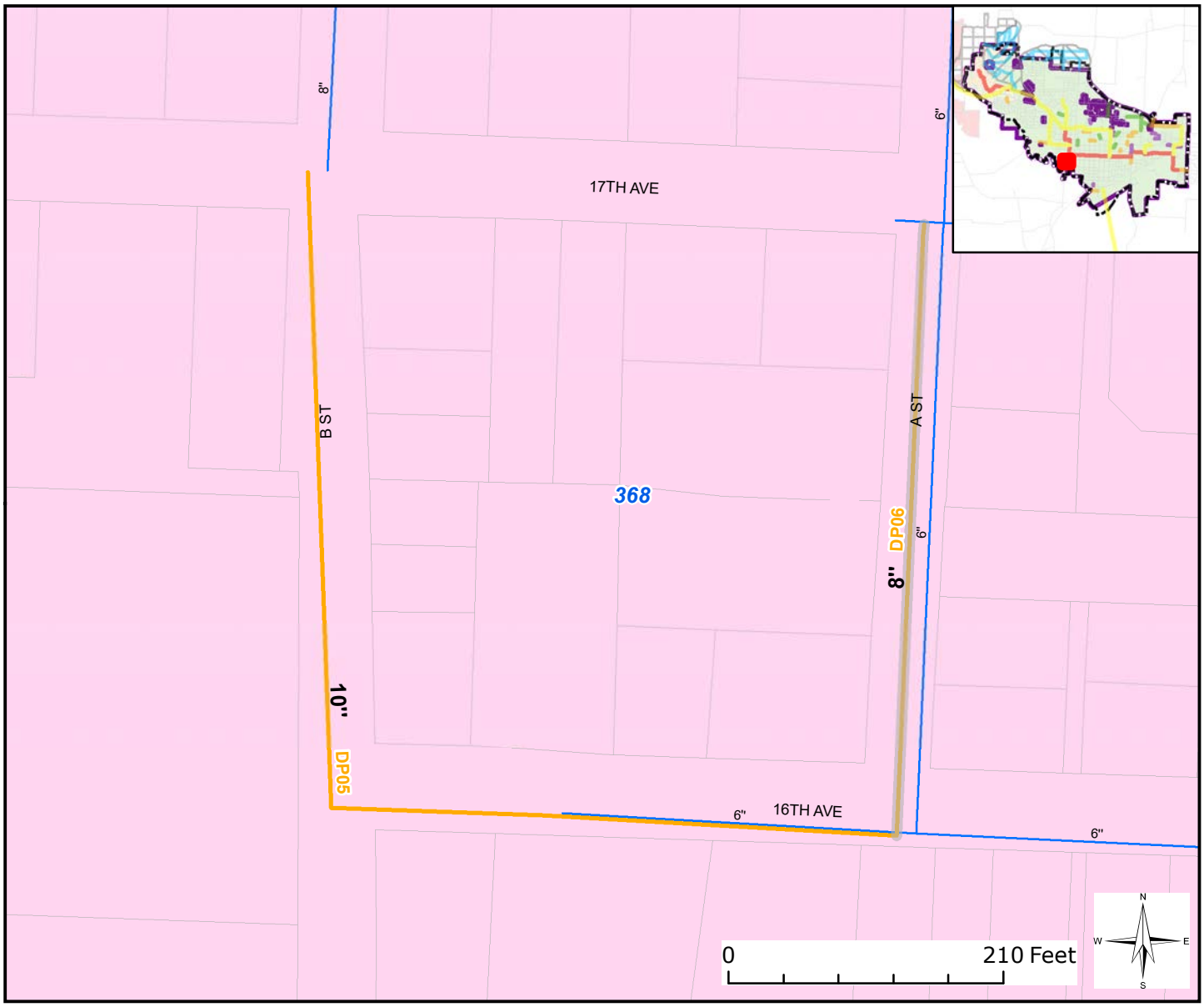


CIP Project HDR_DP03

Project Type: HDR Upsize Existing Pipes
Project Description: Tom McCall Upper Elementary
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $390,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- SRP Improvements
- Prior WMP Improvements, New Piping
- 368

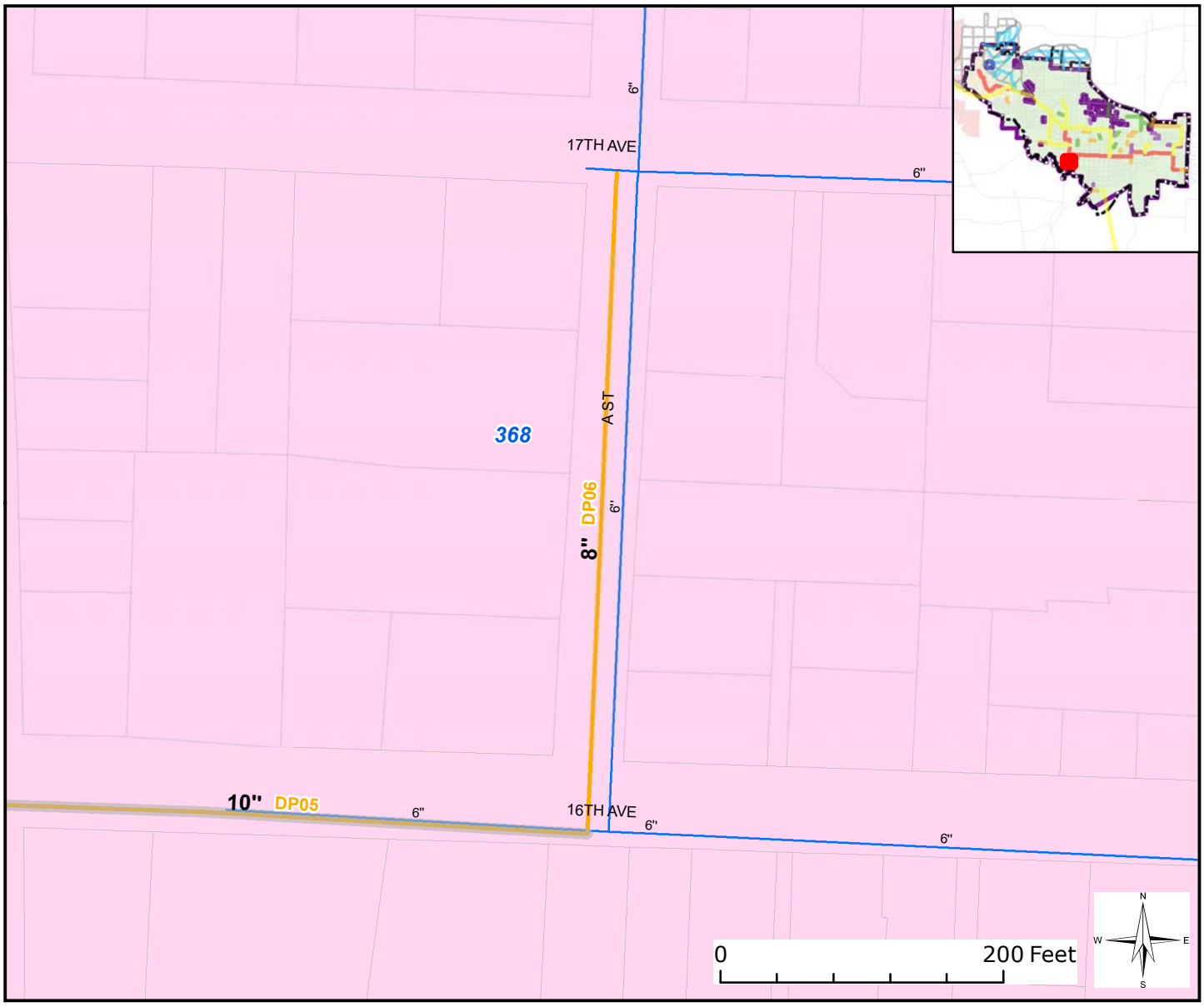
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CIP Project HDR_DP05

Project Type: HDR Upsize Existing Pipes
Project Description: B St and 16th Ave
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $350,000
Project Phasing: As replacement opportunities arise

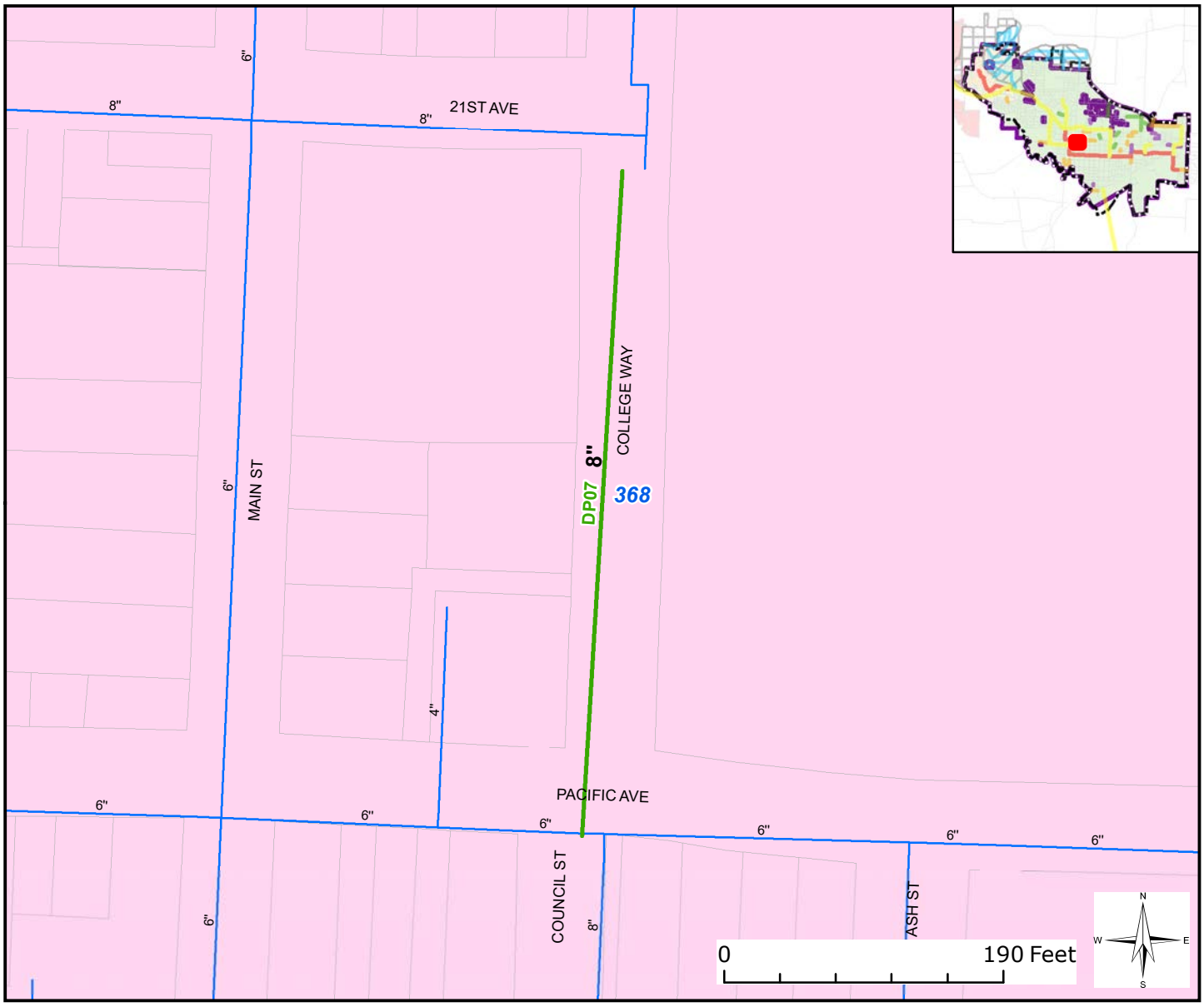
- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- 368



CIP Project HDR_DP06

Project Type: HDR Upsize Existing Pipes
Project Description: A St between 16th and 17th Ave
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $150,000
Project Phasing: As replacement opportunities arise

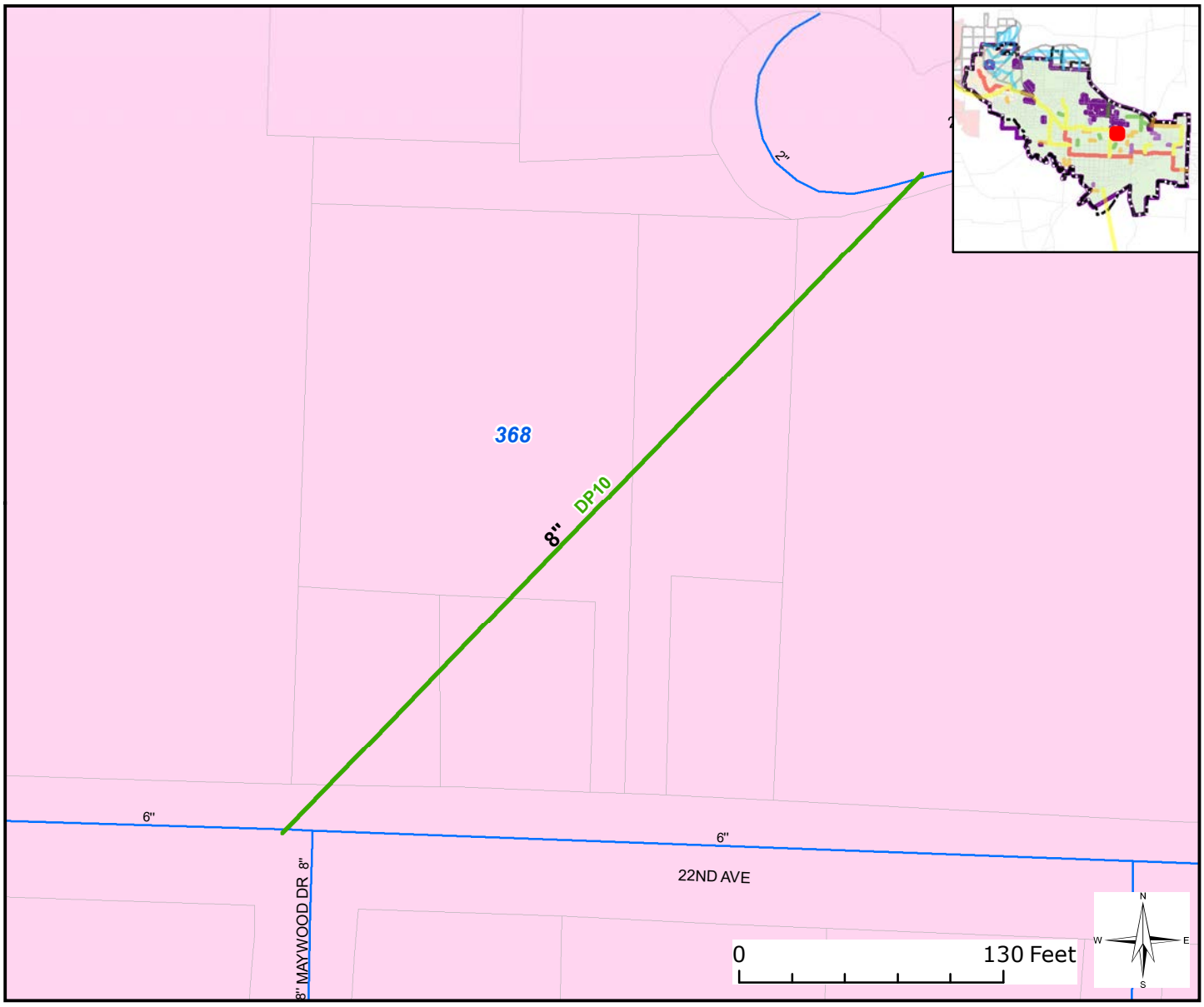
- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- 368



CIP Project HDR_DP07

Project Type: HDR New Pipes
Project Description: College Way connection from Pacific Ave
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $130,000
Project Phasing: As development opportunities arise

PS PumpStation
PRV
Tank
Prior WMP Improvements, Upsize Existing
368

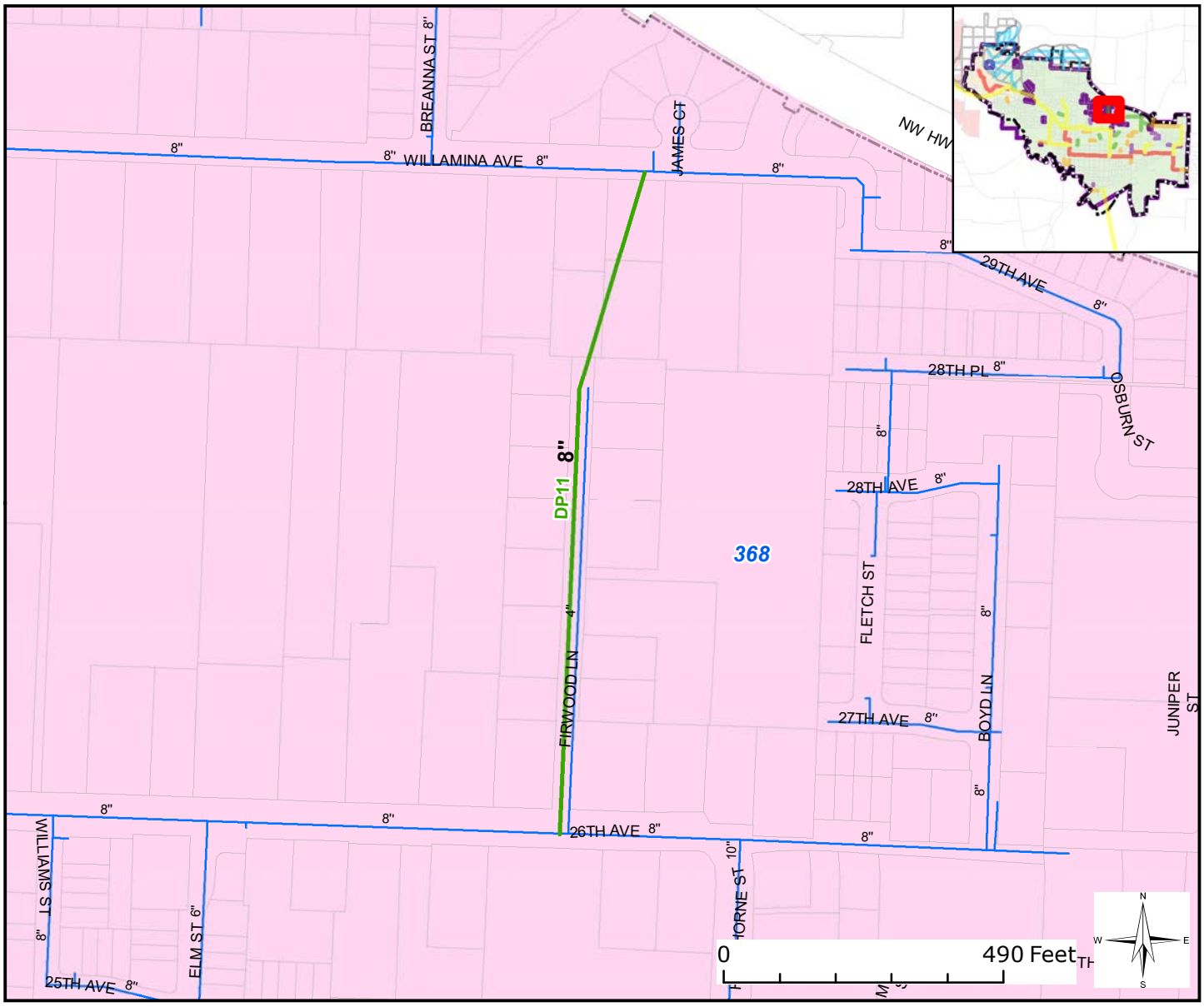


CIP Project HDR_DP10

Project Type: HDR New Pipes
Project Description: Bard Park connection
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $130,000
Project Phasing: As development opportunities arise

PumpStation
PRV
Tank
Prior WMP Improvements, Upsize Existing
368

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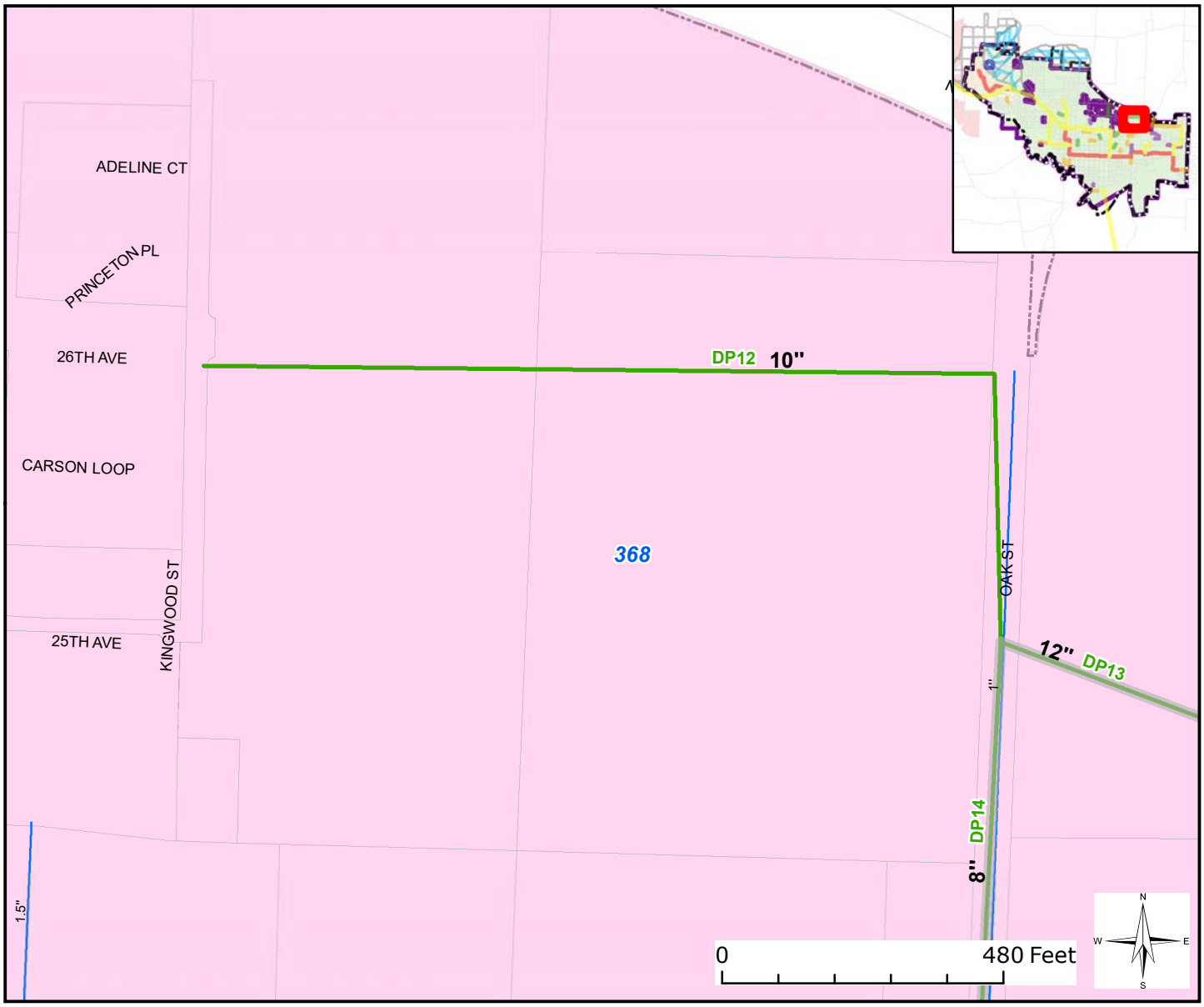


CIP Project HDR_DP11

Project Type: HDR New Pipes
Project Description: Firwood Ln
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $350,000
Project Phasing: As development opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, Upsize Existing
- 368

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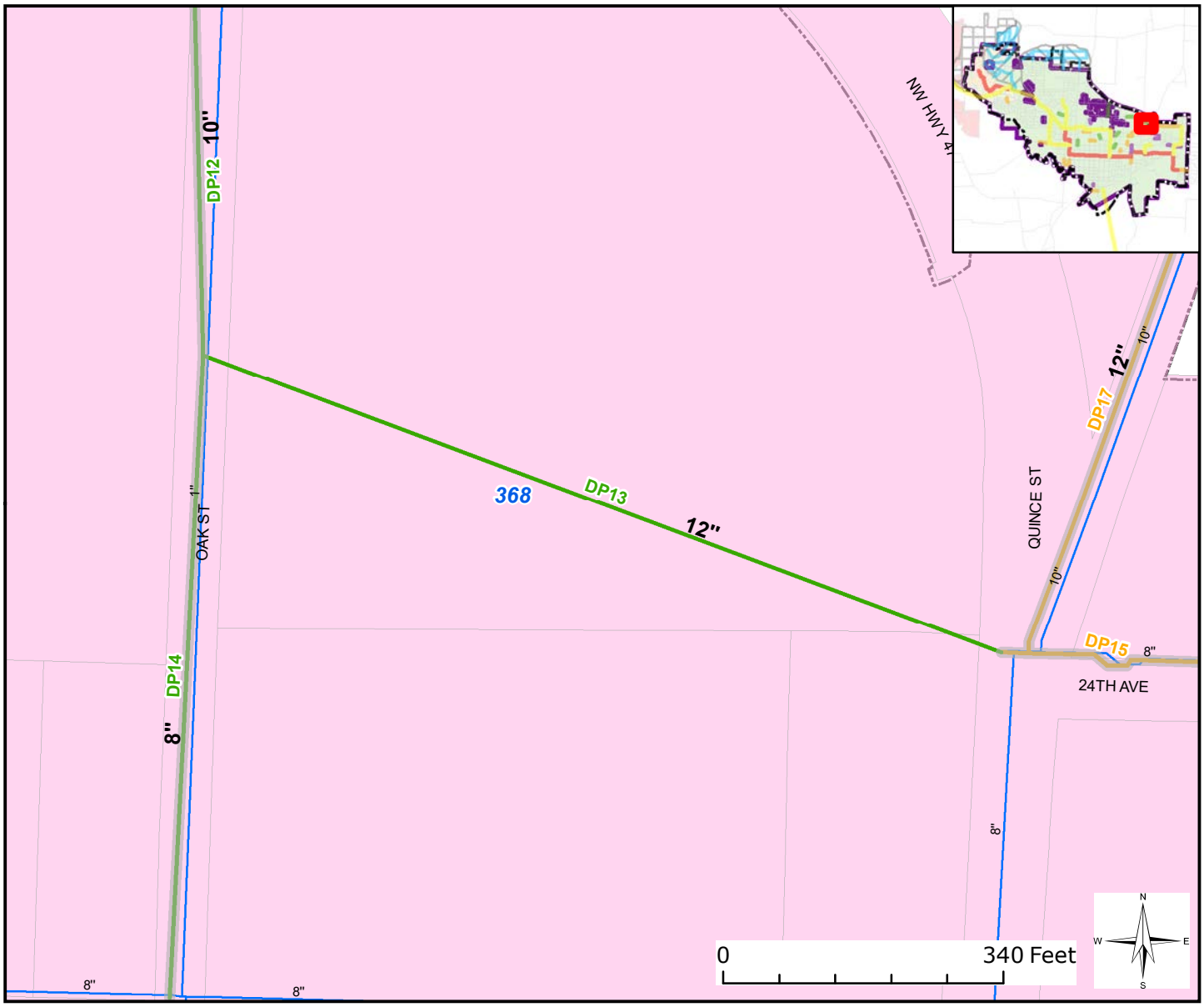


CIP Project HDR_DP12

Project Type: HDR New Pipes
Project Description: Oak St to Kingwood St connection
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $650,000
Project Phasing: As development opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, Upsize Existing
- 368

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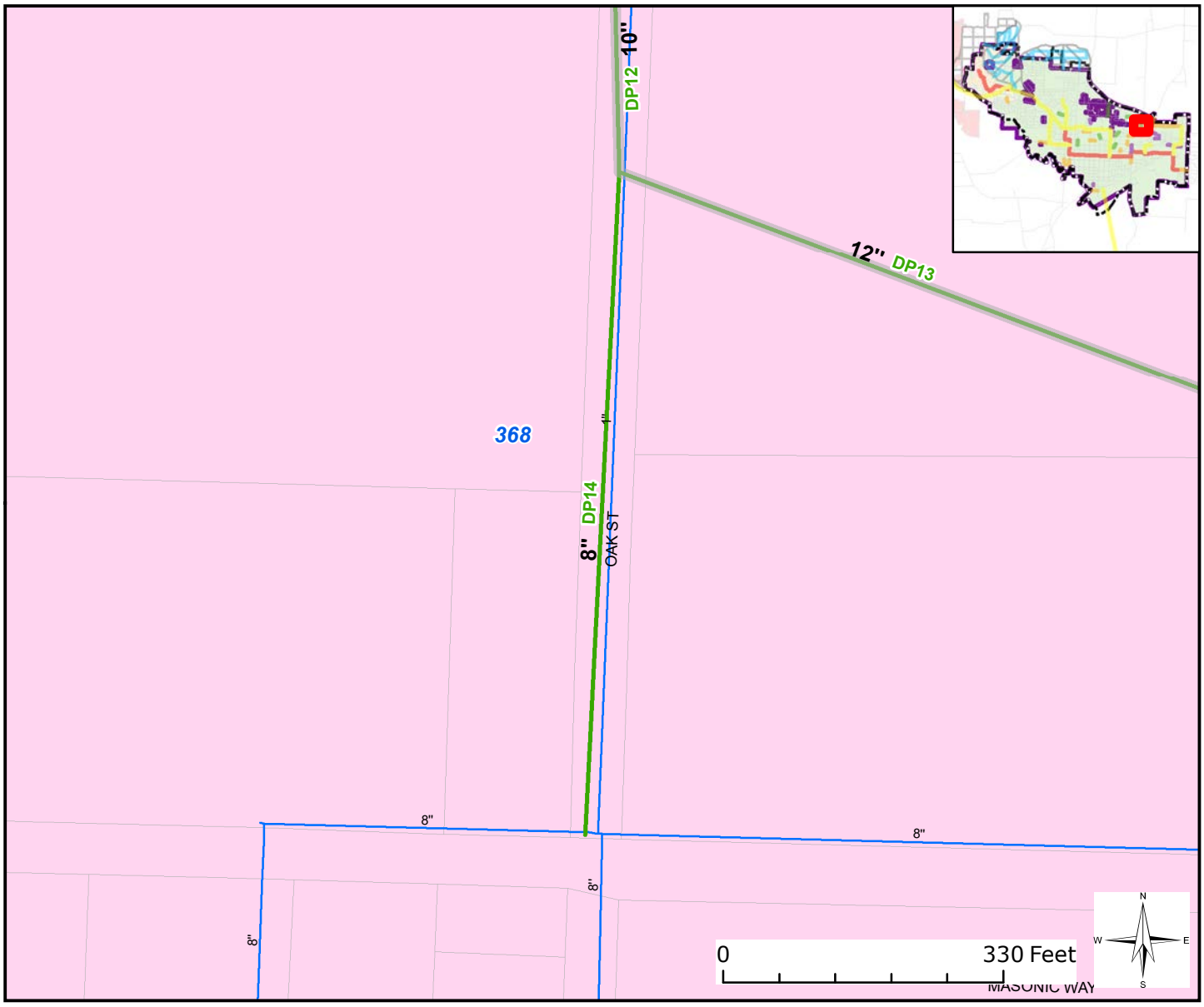


CIP Project HDR_DP13

Project Type: HDR New Pipes
Project Description: Oak St to Nehalem Hwy connection
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $460,000
Project Phasing: As development opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- 368

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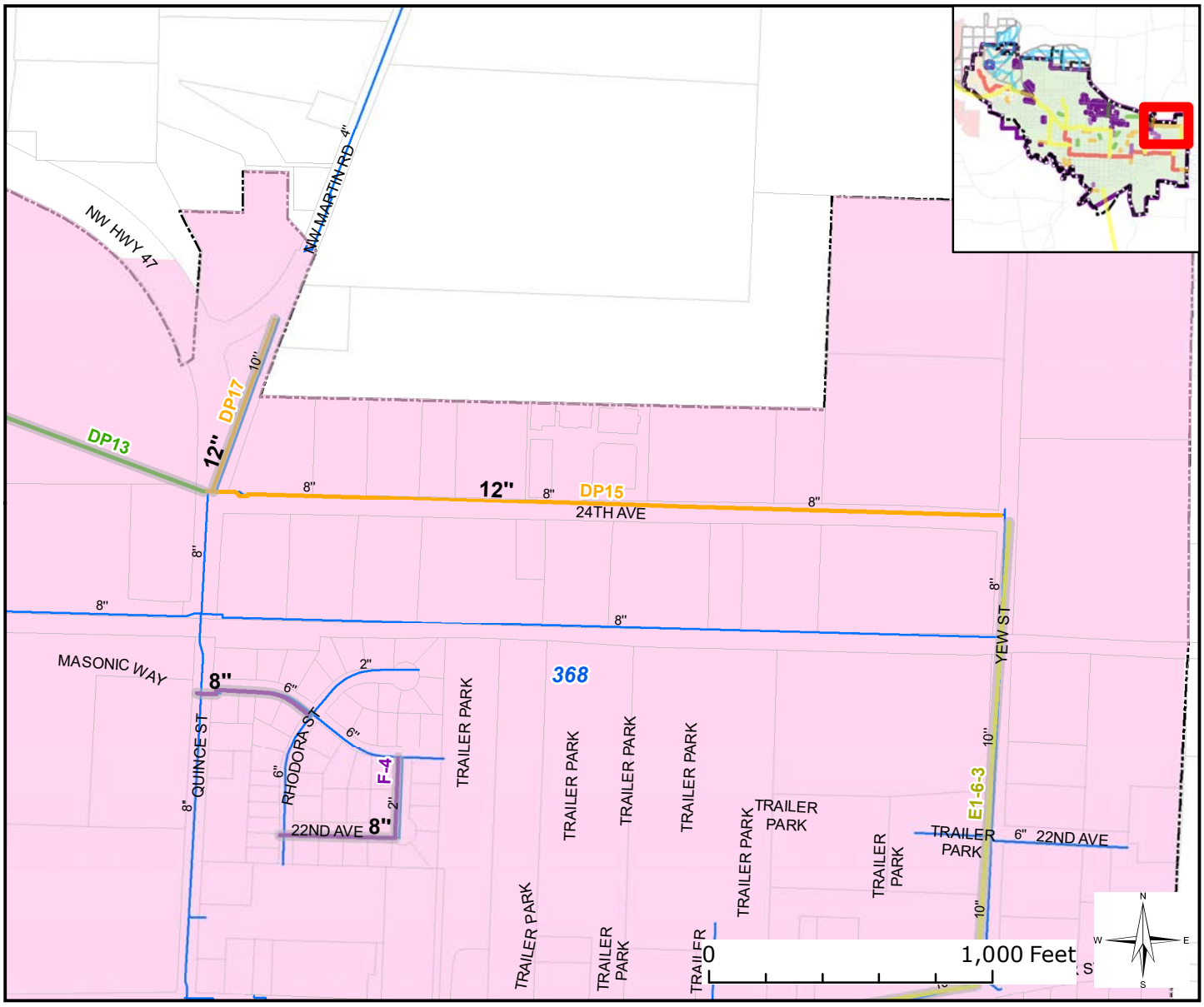


CIP Project HDR_DP14

Project Type: HDR New Pipes
Project Description: Oak St to RR connection
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $240,000
Project Phasing: As development opportunities arise

PS PumpStation
PRV
Tank
Prior WMP Improvements, Upsize Existing
368

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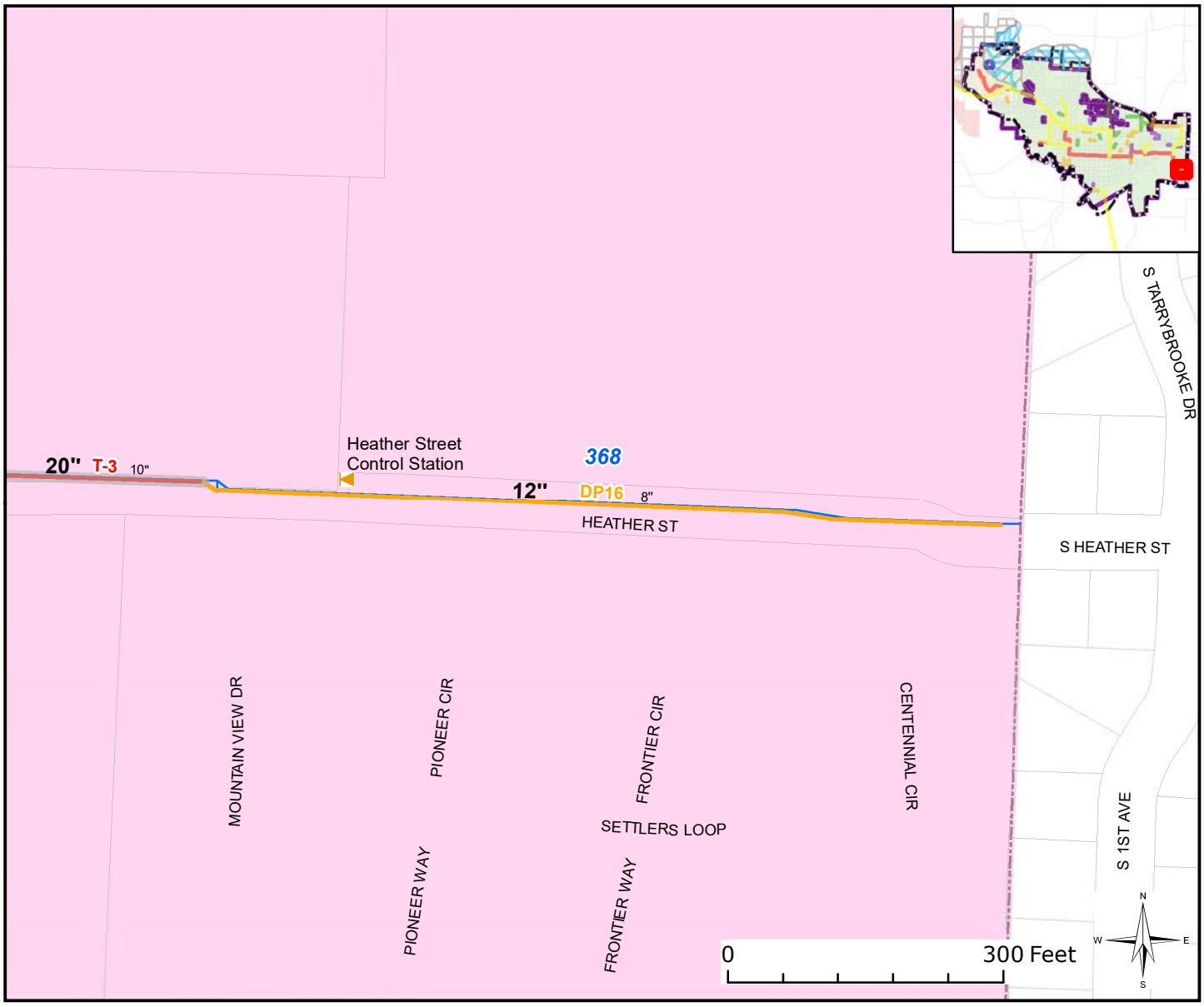


CIP Project HDR_DP15

Project Type: HDR Upsize Existing Pipes
Project Description: 24th Ave east from Nehalem Hwy
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $121,0000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- 368

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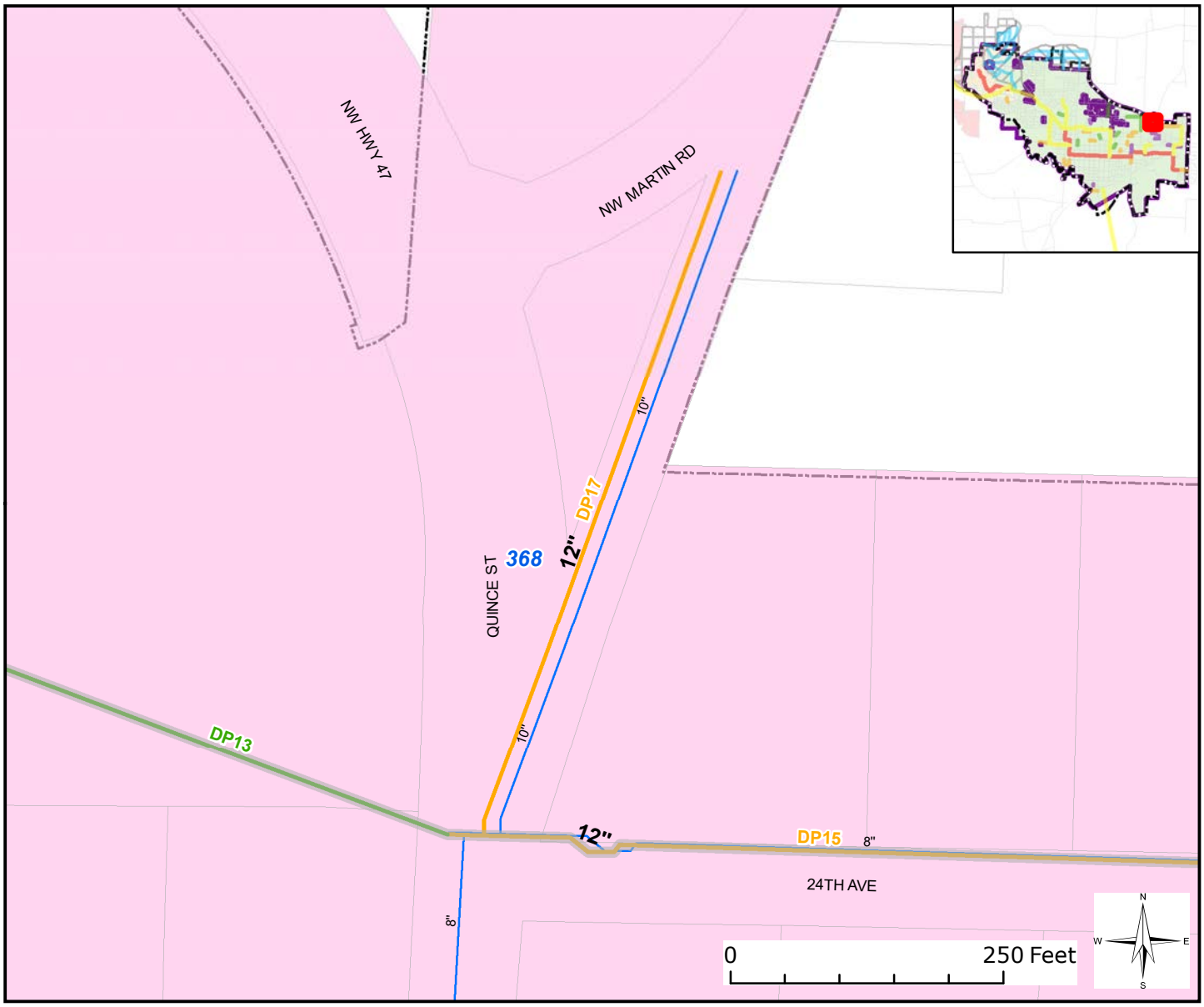


CIP Project HDR_DP16

Project Type: HDR Upsize Existing Pipes
Project Description: Heather St east
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $390,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

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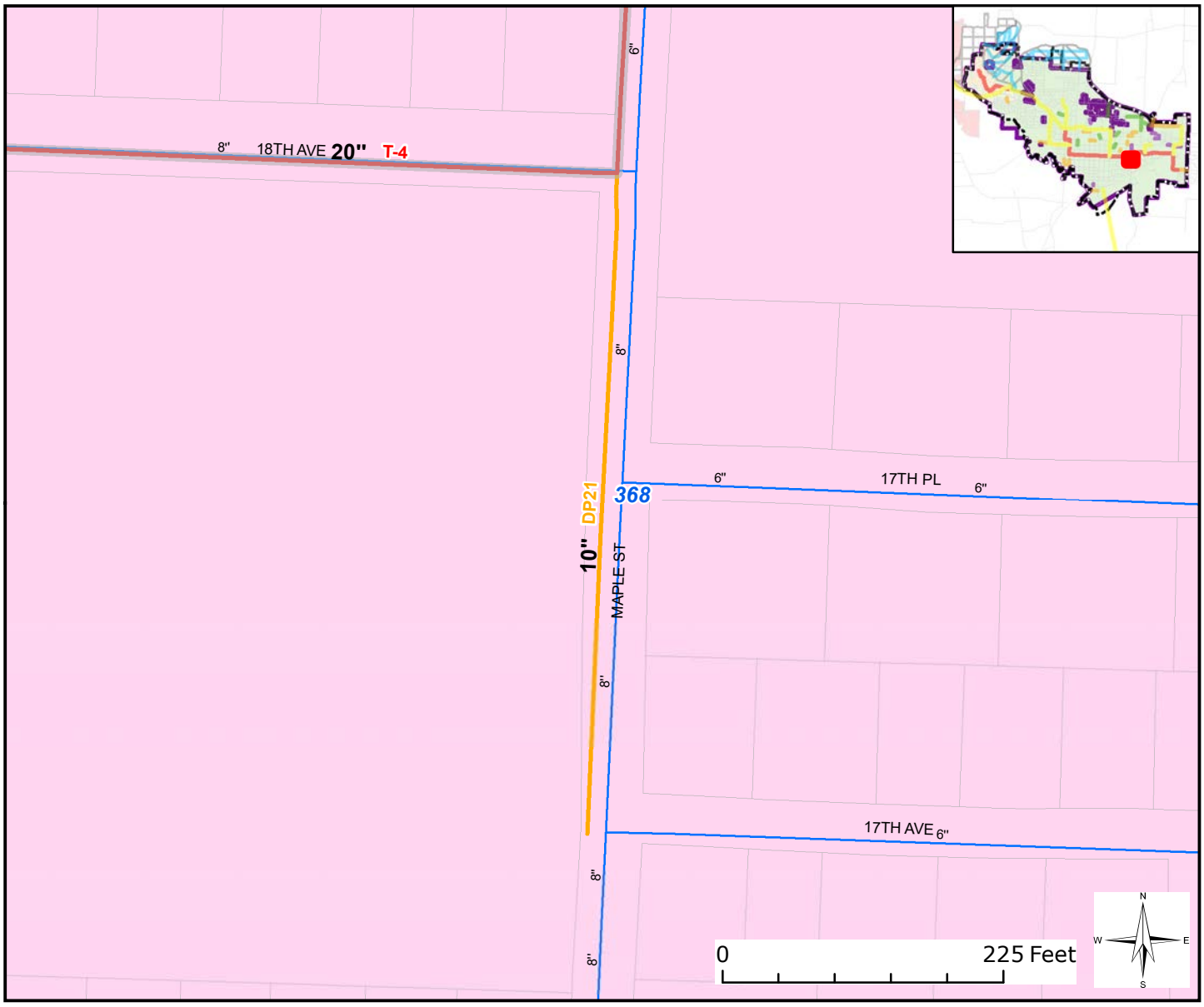


CIP Project HDR_DP17

Project Type: HDR Upsize Existing Pipes
Project Description: NW Martin Rd connector
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $290,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- 368

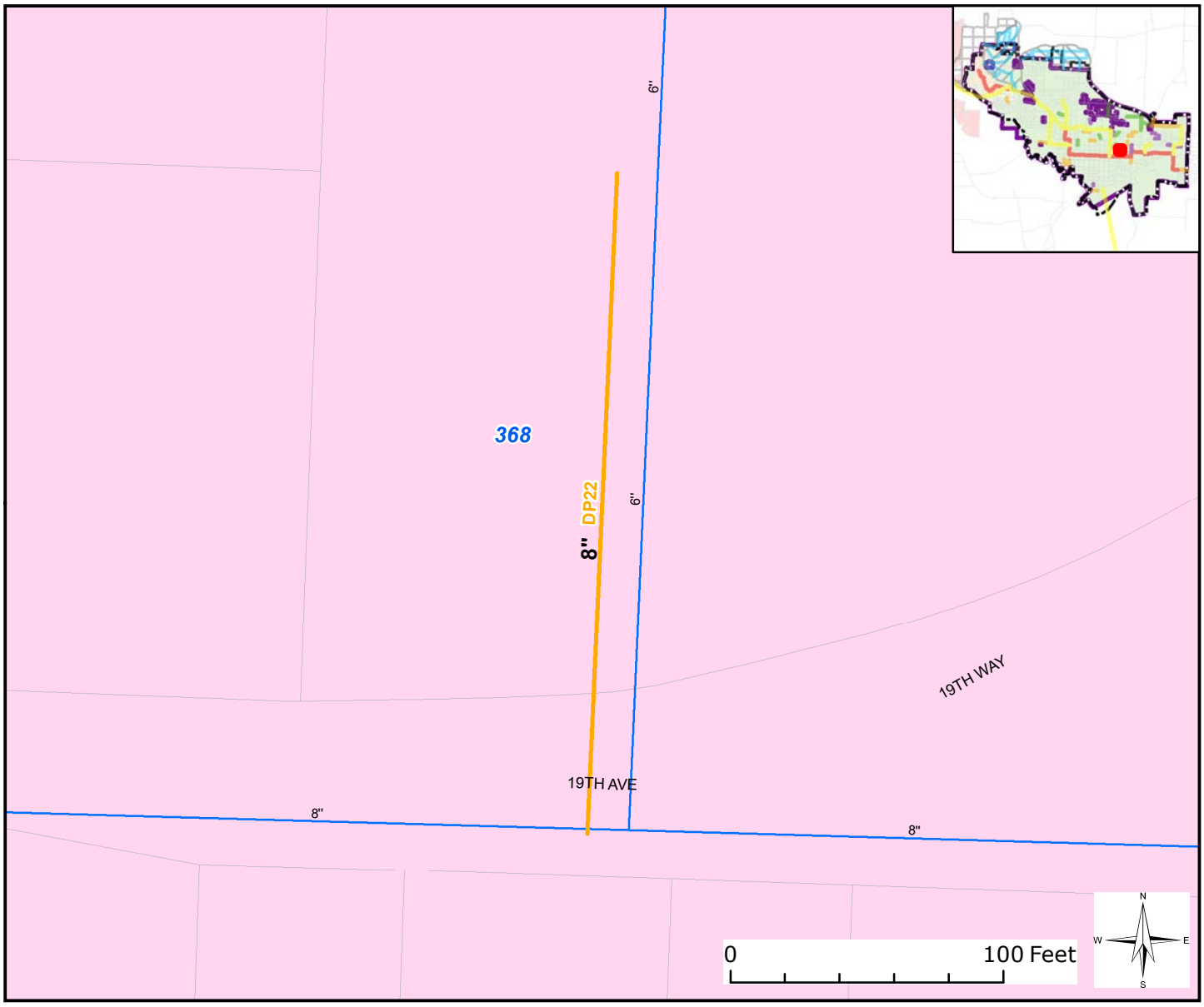
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CIP Project HDR_DP21

Project Type: HDR Upsize Existing Pipes
Project Description: Maple St from 17th Ave to 18th Ave
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $200,000
Project Phasing: As replacement opportunities arise

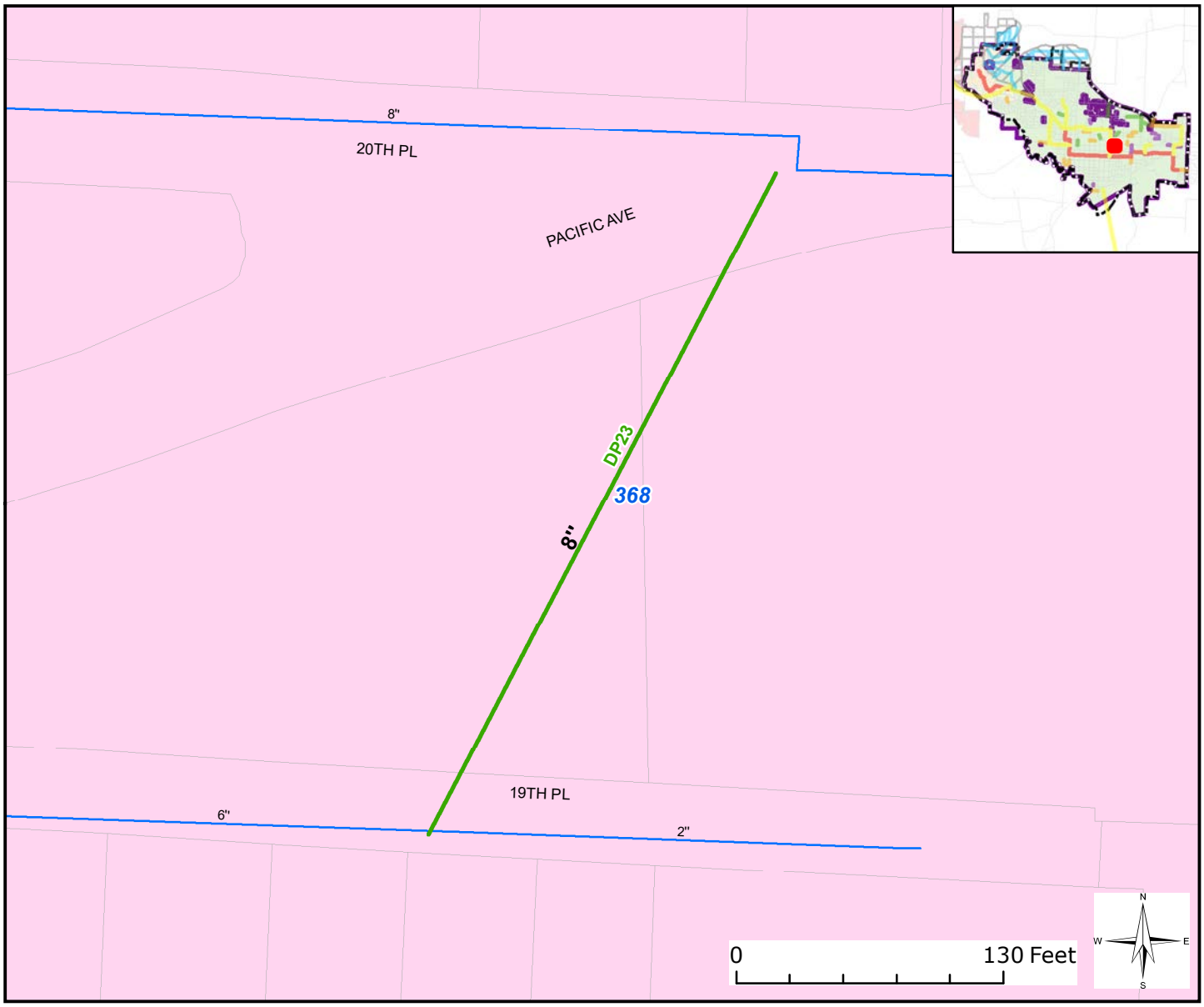
- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368



CIP Project HDR_DP22

Project Type: HDR Upsize Existing Pipes
Project Description: 19th Ave Safeway
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $80,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- 368

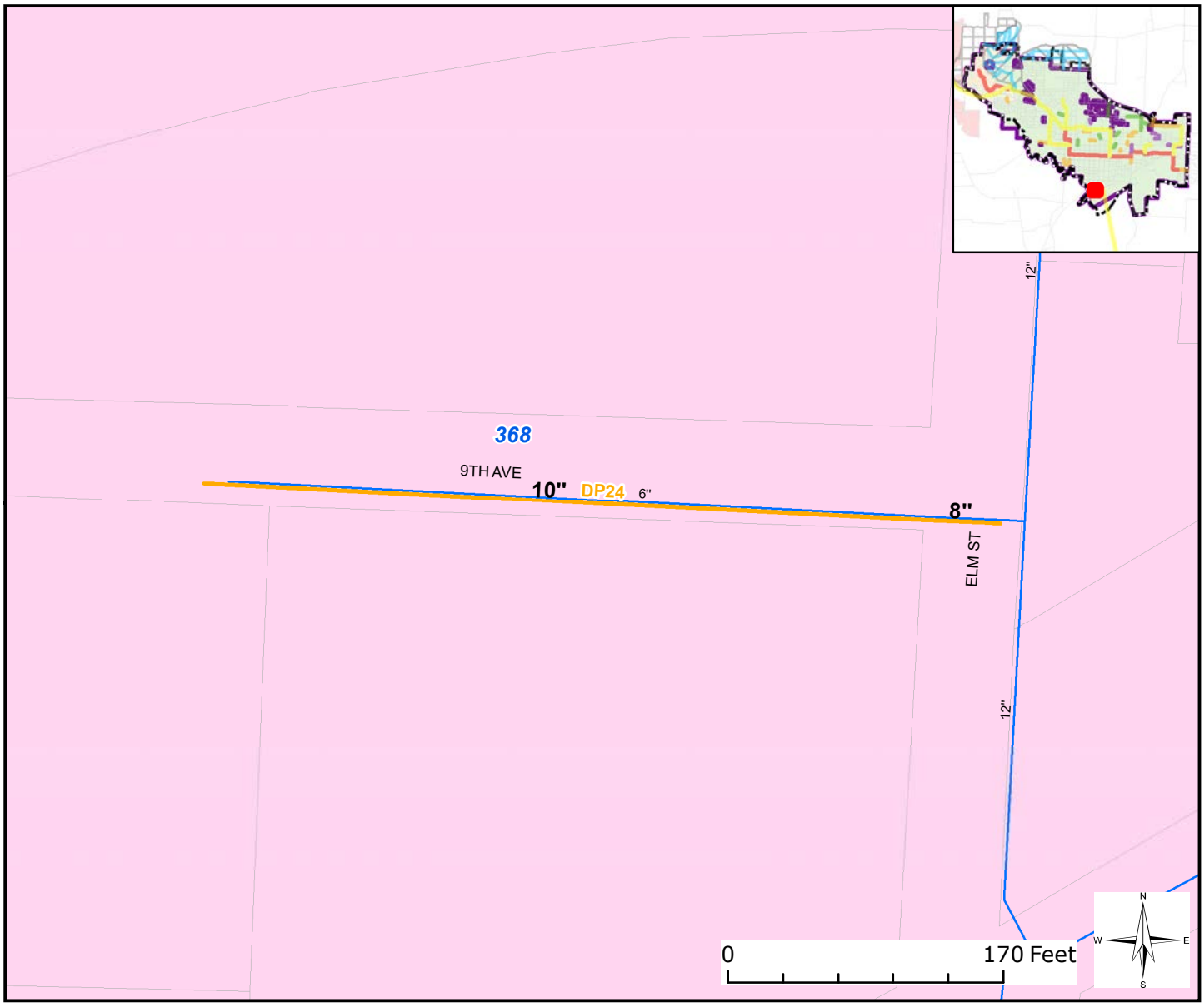


CIP Project HDR_DP23

Project Type: HDR New Pipes
Project Description: 19th Pl to Pacific Ave connector near Les Schwab
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $110,000
Project Phasing: As development opportunities arise

PumpStation
PRV
Tank
Prior WMP Improvements, Upsize Existing
368

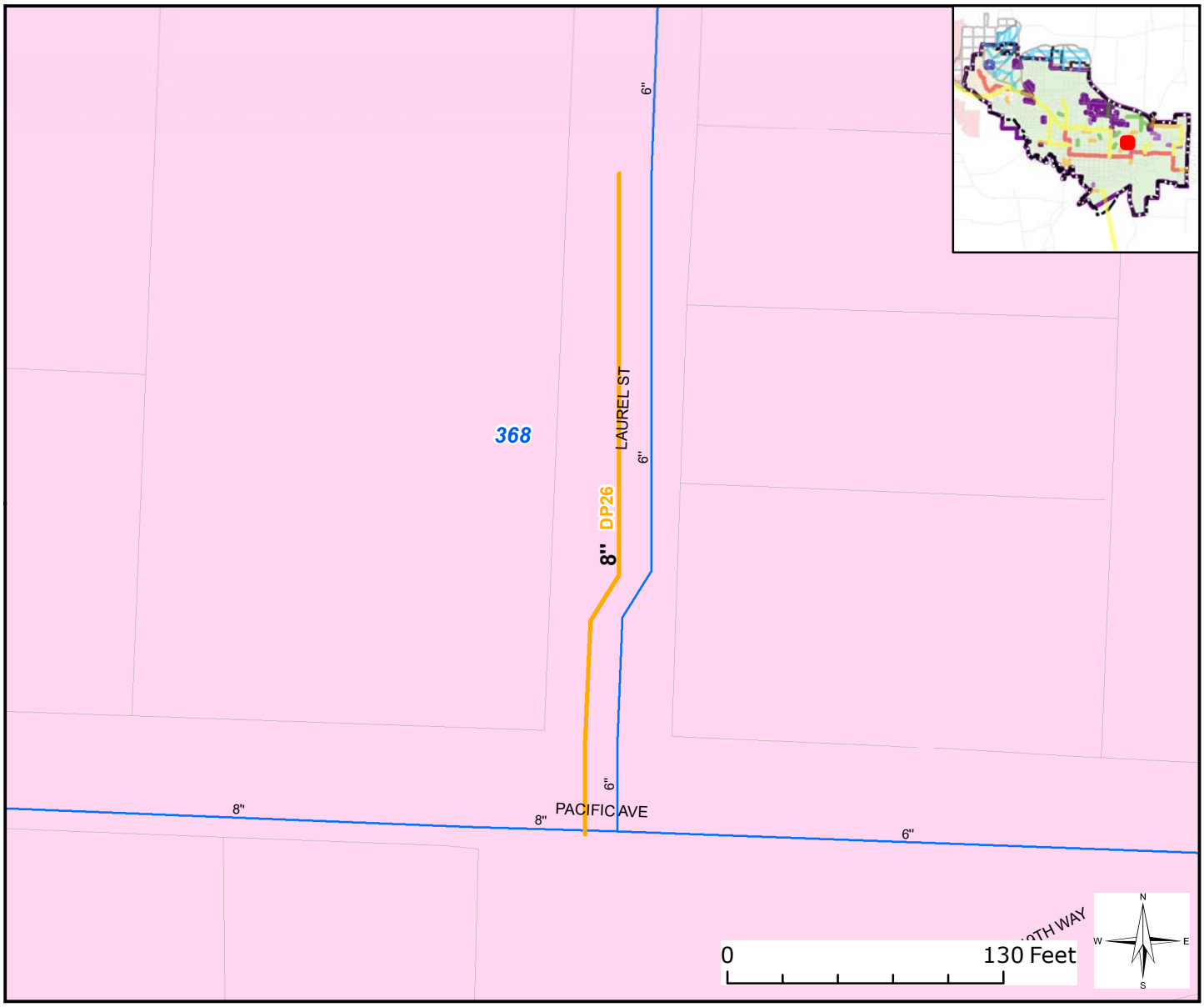
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CIP Project HDR_DP24

Project Type: HDR Upsize Existing Pipes
Project Description: 9th Ave from Elm St
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $180,000
Project Phasing: As replacement opportunities arise

PumpStation
PRV
Tank
Prior WMP Improvements, New Piping
368

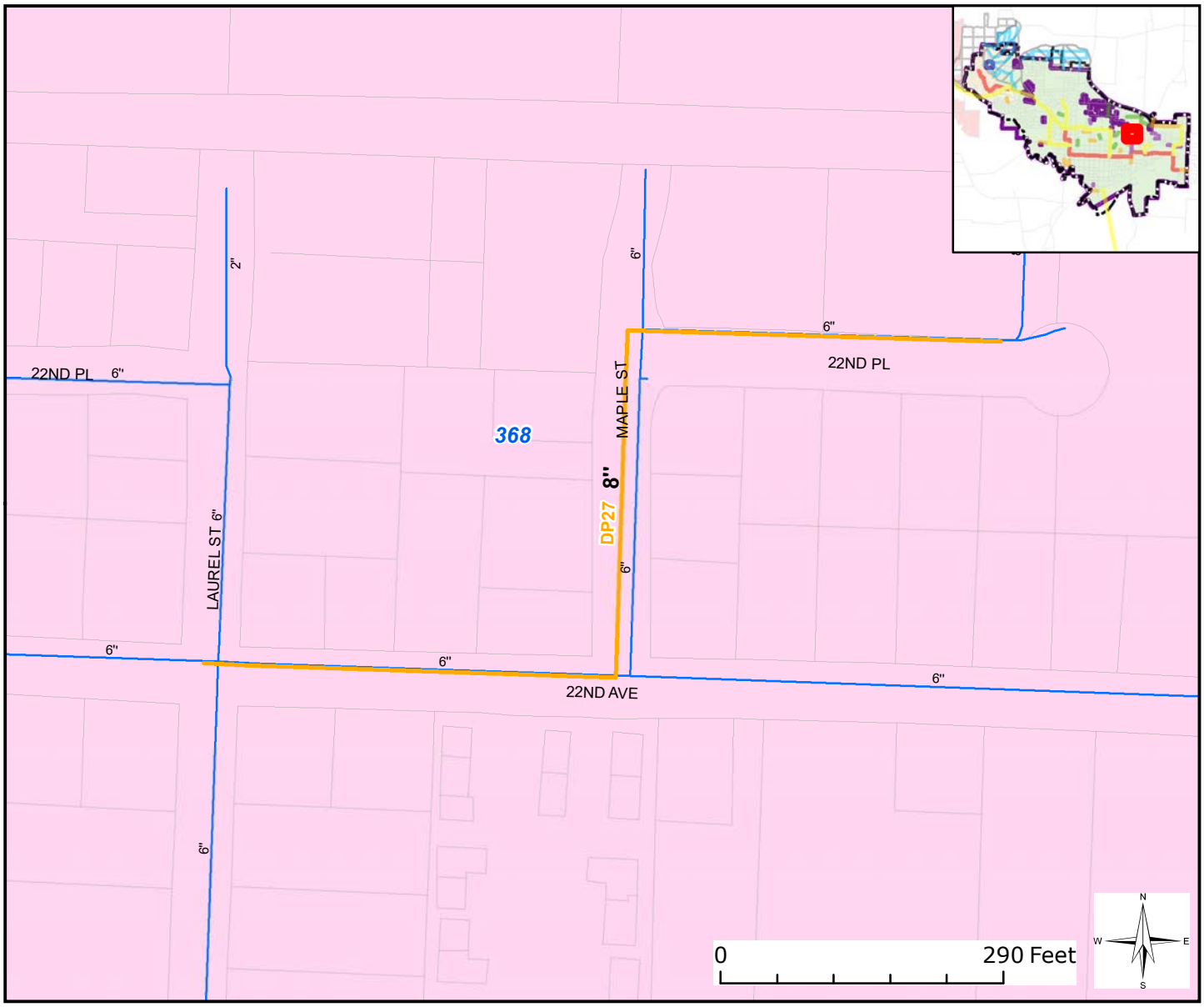


CIP Project HDR_DP26

Project Type: HDR Upsize Existing Pipes
Project Description: Laurel St north from Pacific Ave
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $100,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- 368

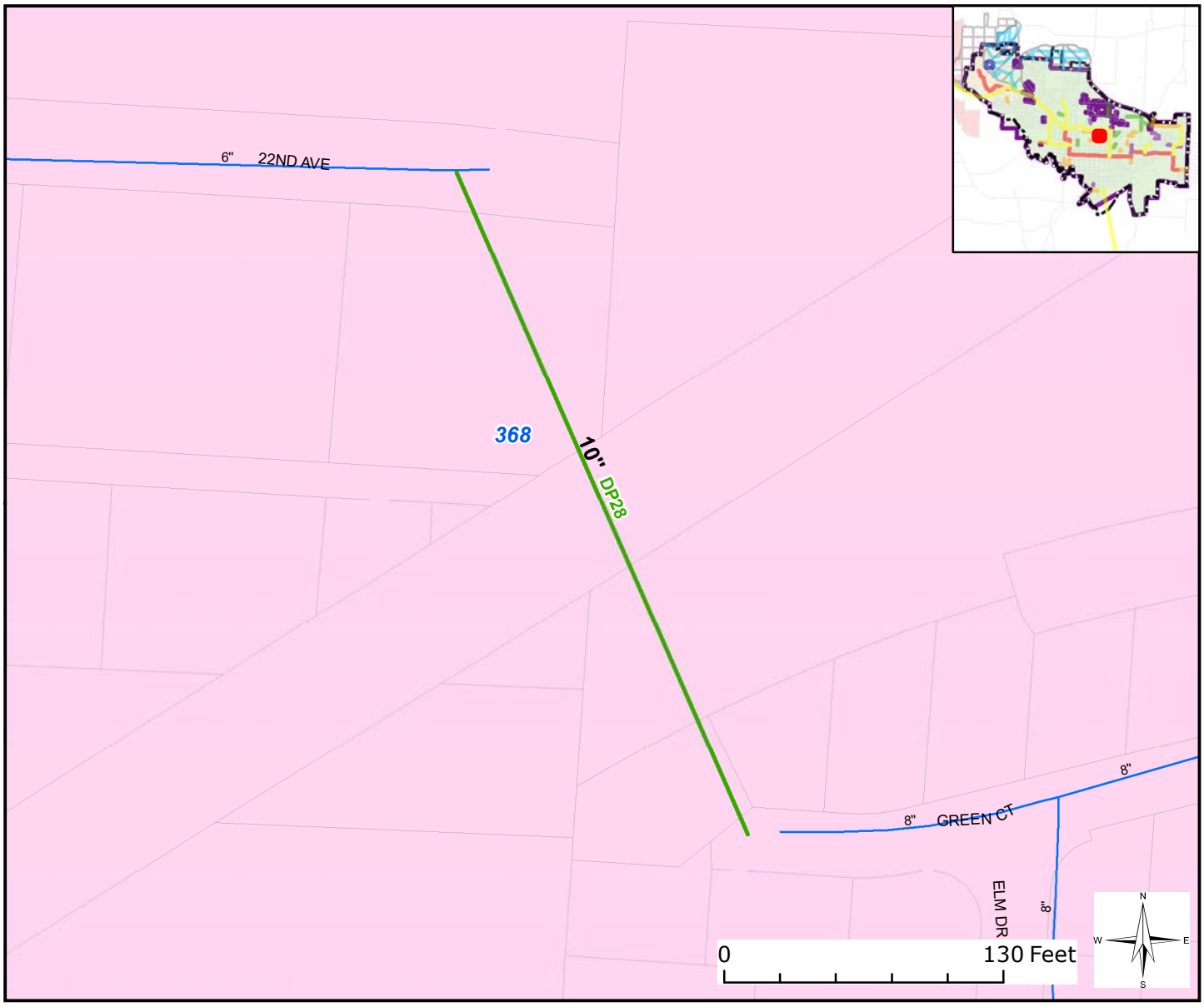
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CIP Project HDR_DP27

Project Type: HDR Upsize Existing Pipes
Project Description: 22nd Ave, Maple St, and 22nd Pl
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $350,000
Project Phasing: As replacement opportunities arise

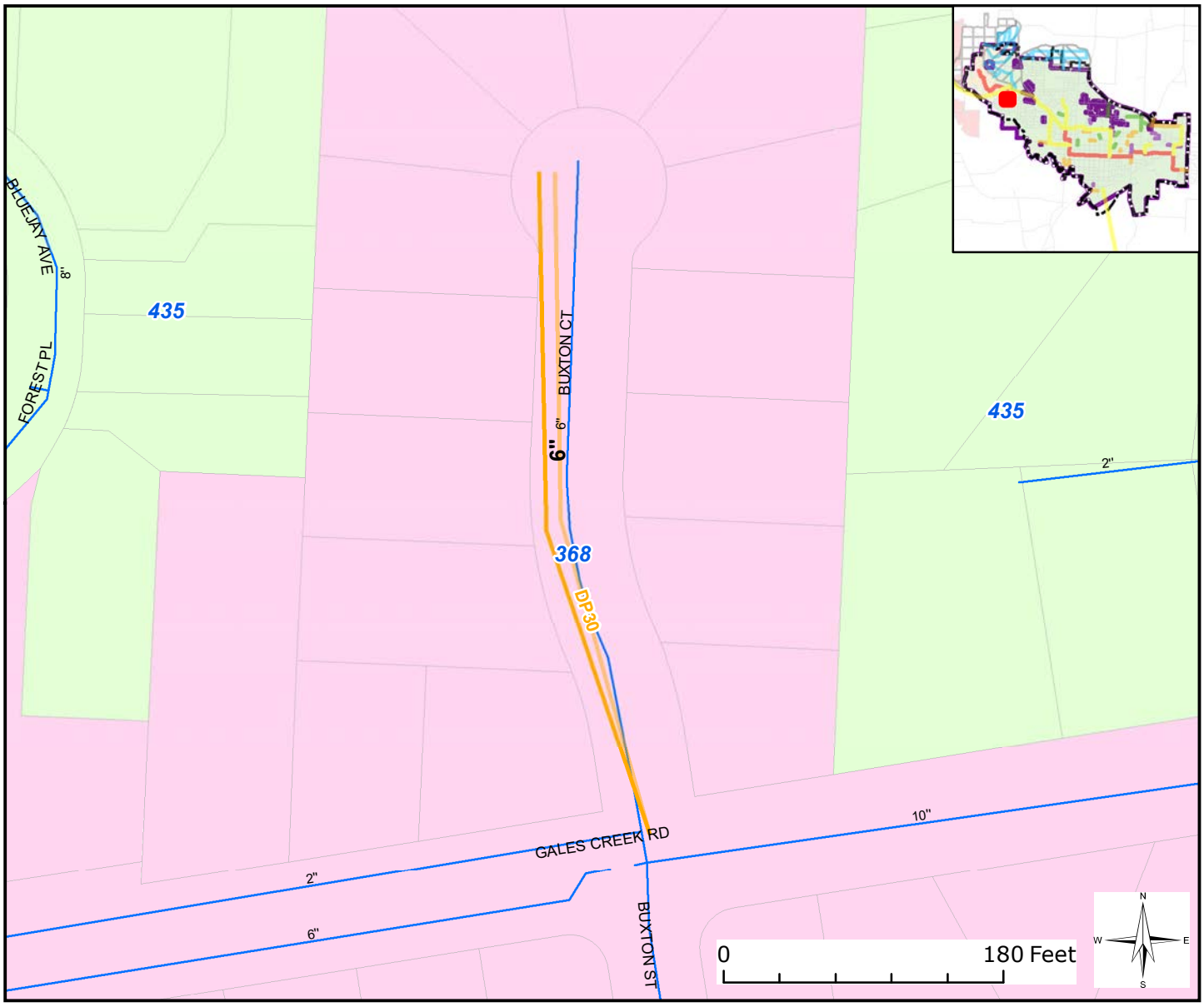
PS PumpStation
PRV
Tank
Prior WMP Improvements, New Piping
368



CIP Project HDR_DP28

Project Type: HDR New Pipes
Project Description: RR crossing from Green Ct to 22nd Ave
Project Need: Improve system looping
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $130,000
Project Phasing: As development opportunities arise

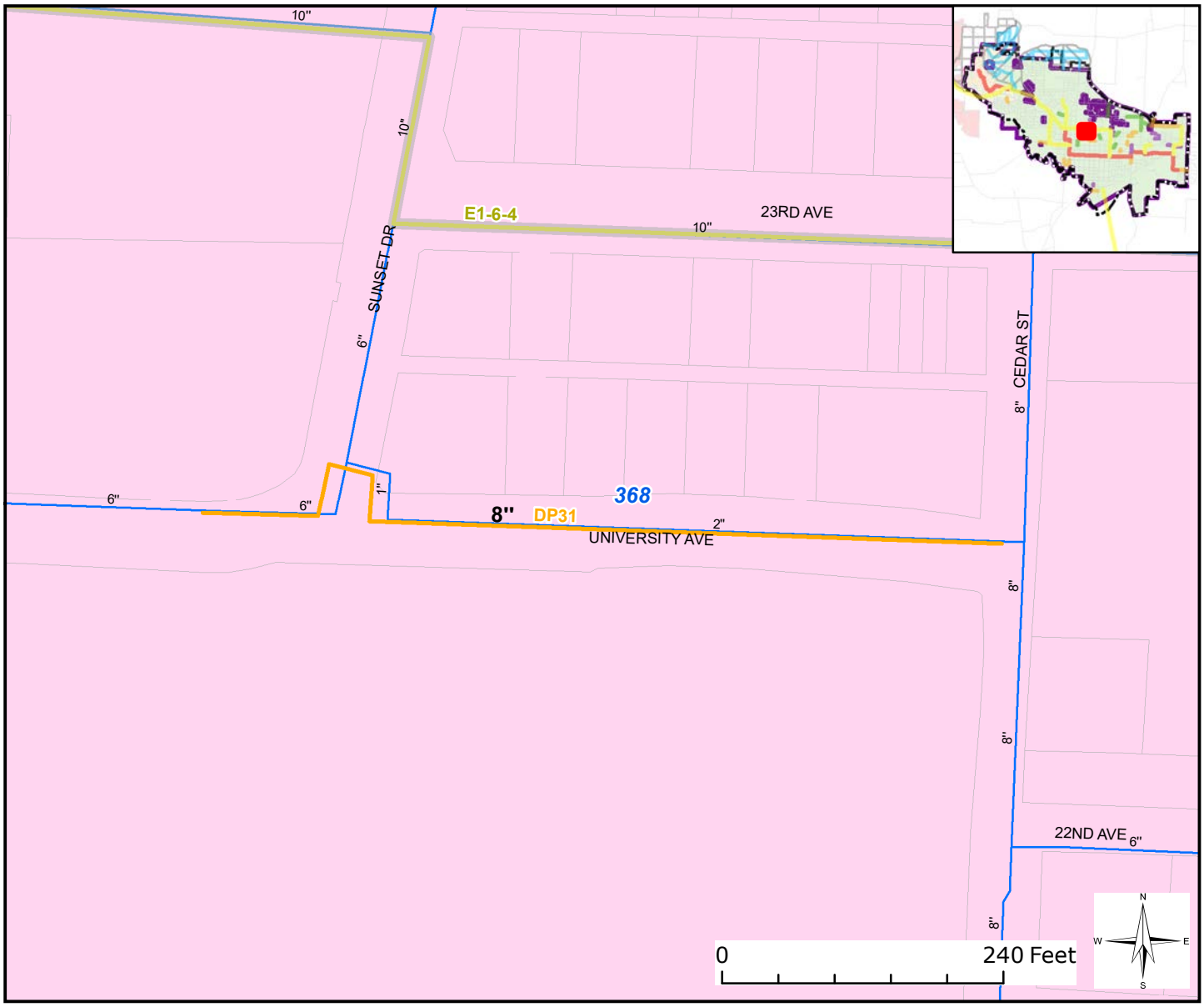
- PumpStation
- PRV
- Tank
- Prior WMP Improvements, Upsize Existing
- 368



CIP Project HDR_DP30

Project Type: HDR Upsize Existing Pipes
Project Description: Buxton Ct
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $130,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- Prior WMP Improvements, New Piping
- 368
- 435

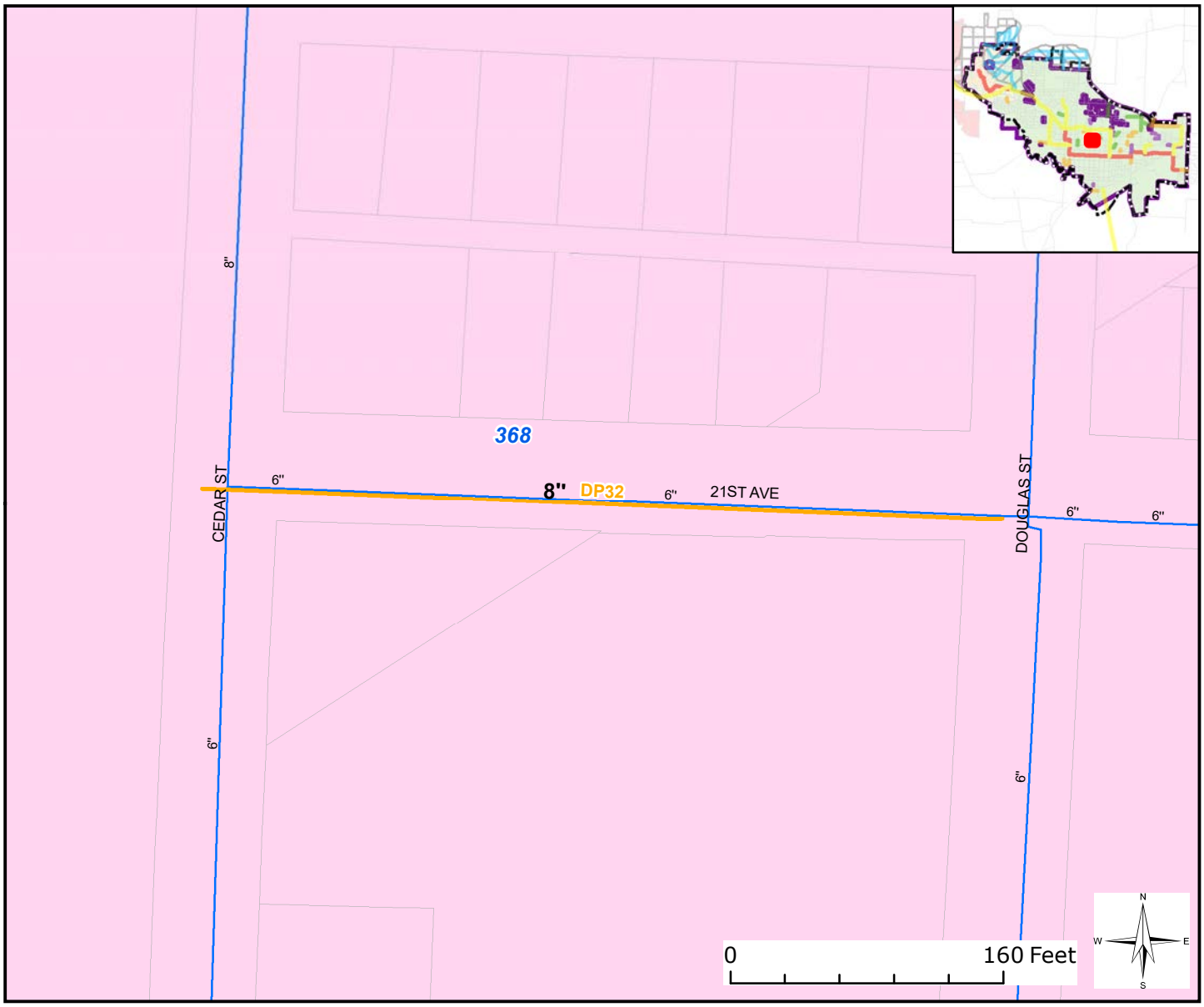


CIP Project HDR_DP31

Project Type: HDR Upsize Existing Pipes
Project Description: University Ave from Cedar St to Sunset Dr
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $230,000
Project Phasing: As replacement opportunities arise

- PumpStation
- PRV
- Tank
- SRP Improvements
- Prior WMP Improvements, New Piping
- 368

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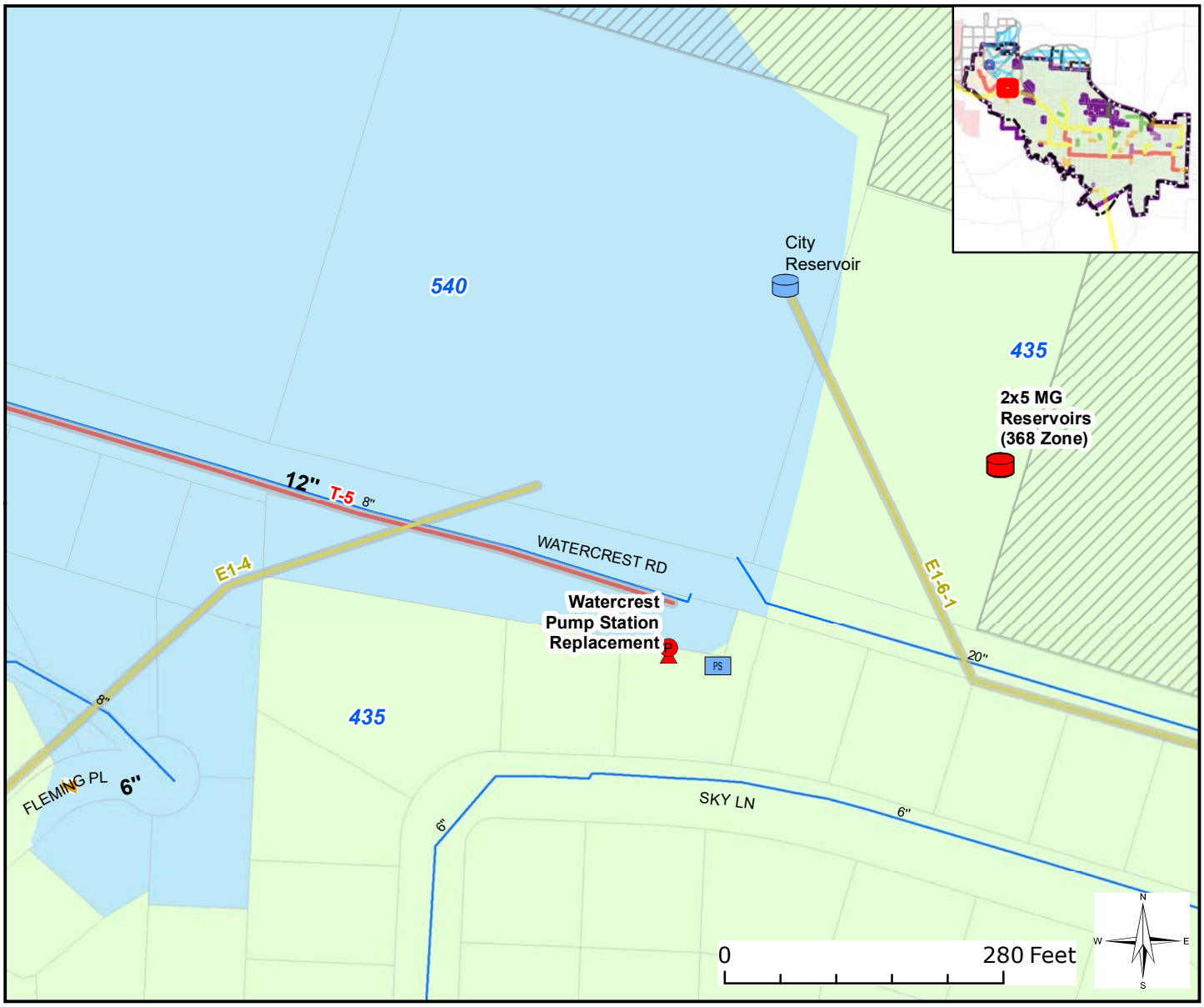


CIP Project HDR_DP32

Project Type: HDR Upsize Existing Pipes
Project Description: 21st Ave from Douglas St to Cedar St
Project Need: Improve distribution system
Expected Timeframe: 11-20 Years
Priority: Low
Project Cost: $150,000
Project Phasing: As replacement opportunities arise

PS PumpStation
PRV
Tank
Prior WMP Improvements, New Piping
368

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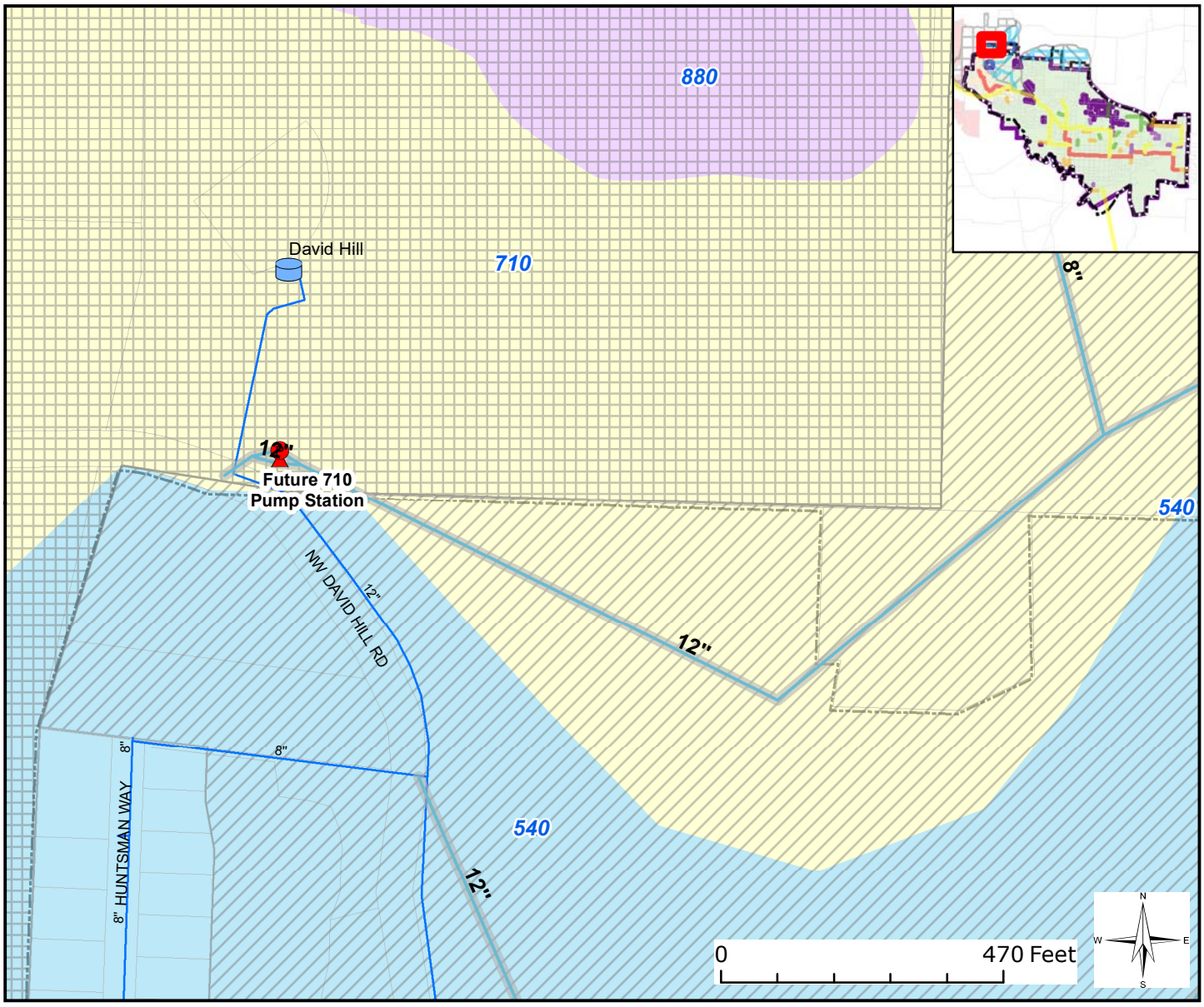


CIP Project PS-1

Project Type: Pump Station
Project Description: Replace and improve existing Watercrest Pump Station
Project Need: Improve resiliency and reliability of existing infrastructure, provide reliable supply to future high elevation customers
Expected Timeframe: 0-5 Years
Priority: High
Project Cost: $1,200,000
Project Phasing:

- PS PumpStation
- PRV
- Tank
- P Proposed Pump Station
- Proposed Reservoir
- SRP Improvements
- Future Development w/in UGB
- Transmission Improvements
- 435
- 540
- David Hill UGB

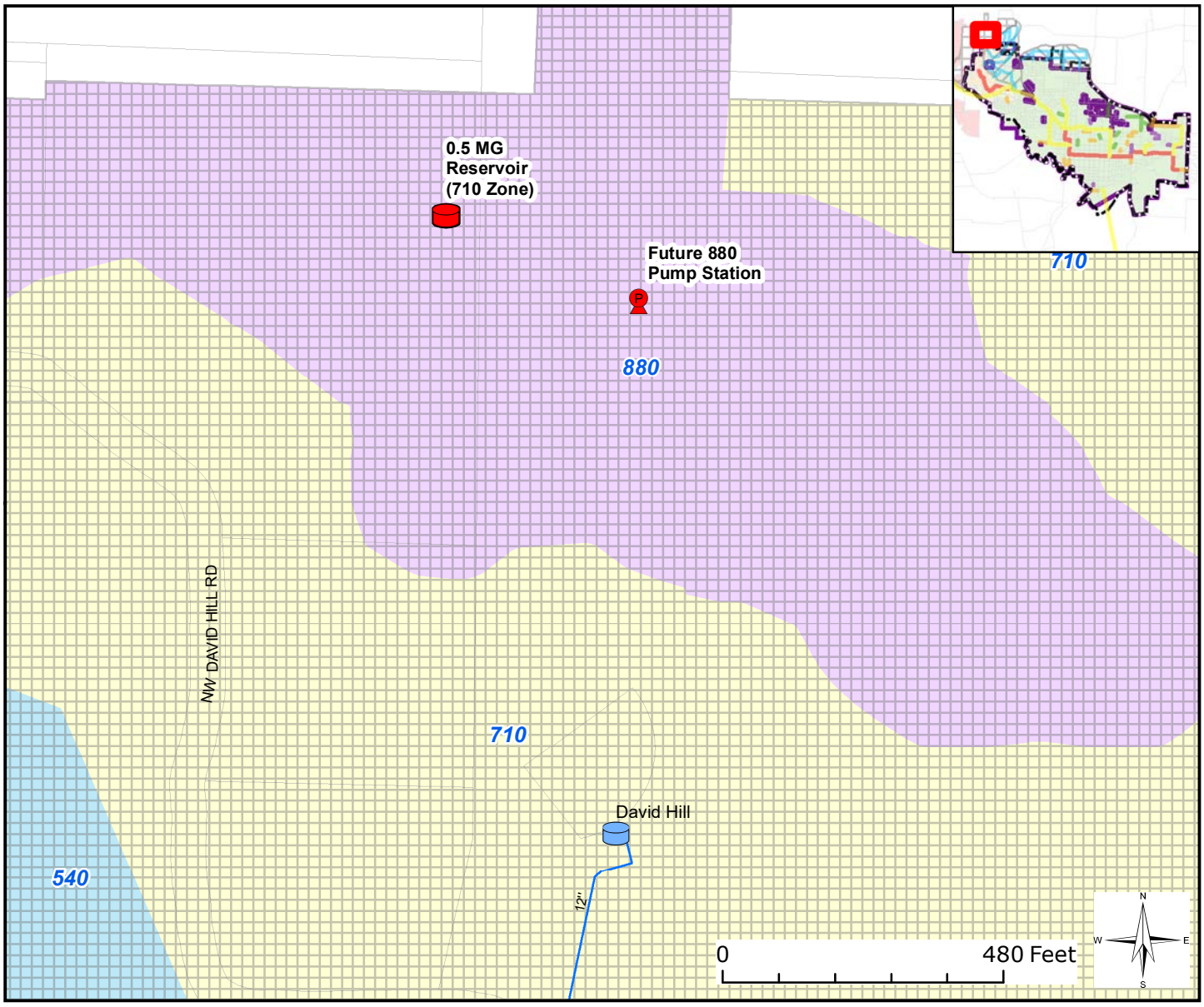
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CIP Project PS-2

Project Type: Pump Station
Project Description: New 710 Zone constant pressure pump station
Project Need: Serve future customers above existing service elevations
Expected Timeframe: 0-5 Years
Priority: Medium
Project Cost: $900,000
Project Phasing: As development requires

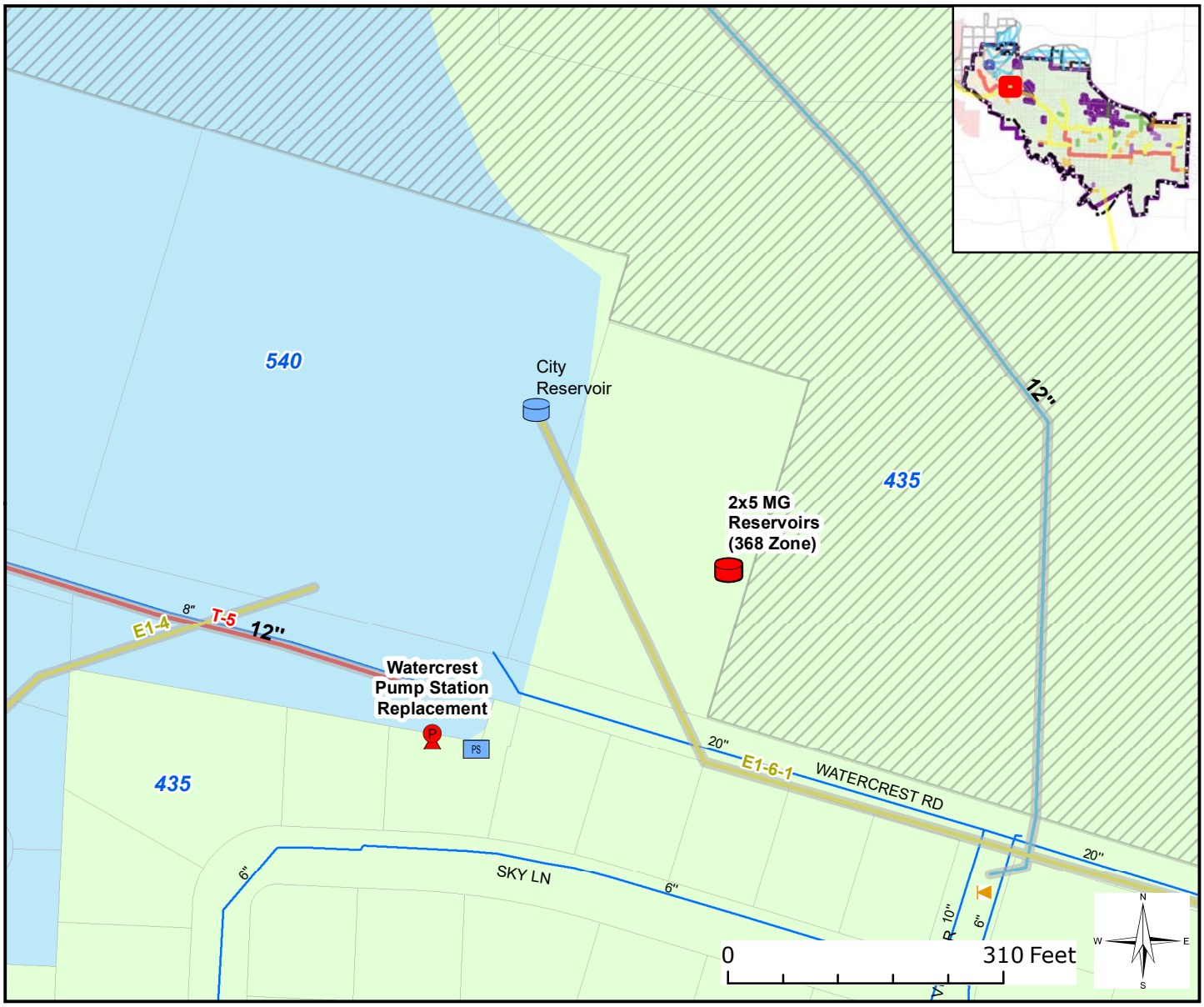
- PumpStation
- PRV
- Tank
- Proposed Pump Station
- Future Development w/in UGB
- 540
- 710, Future
- 880, Future
- David Hill URA
- David Hill UGB



CIP Project PS-3

Project Type: Pump Station
Project Description: New 880 Zone constant pressure pump station
Project Need: Serve future customers above future 710 service elevation
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $850,000
Project Phasing: As development requires

- PumpStation
- PRV
- Tank
- Proposed Pump Station
- Proposed Reservoir
- 540
- 710, Future
- 880, Future
- David Hill URA

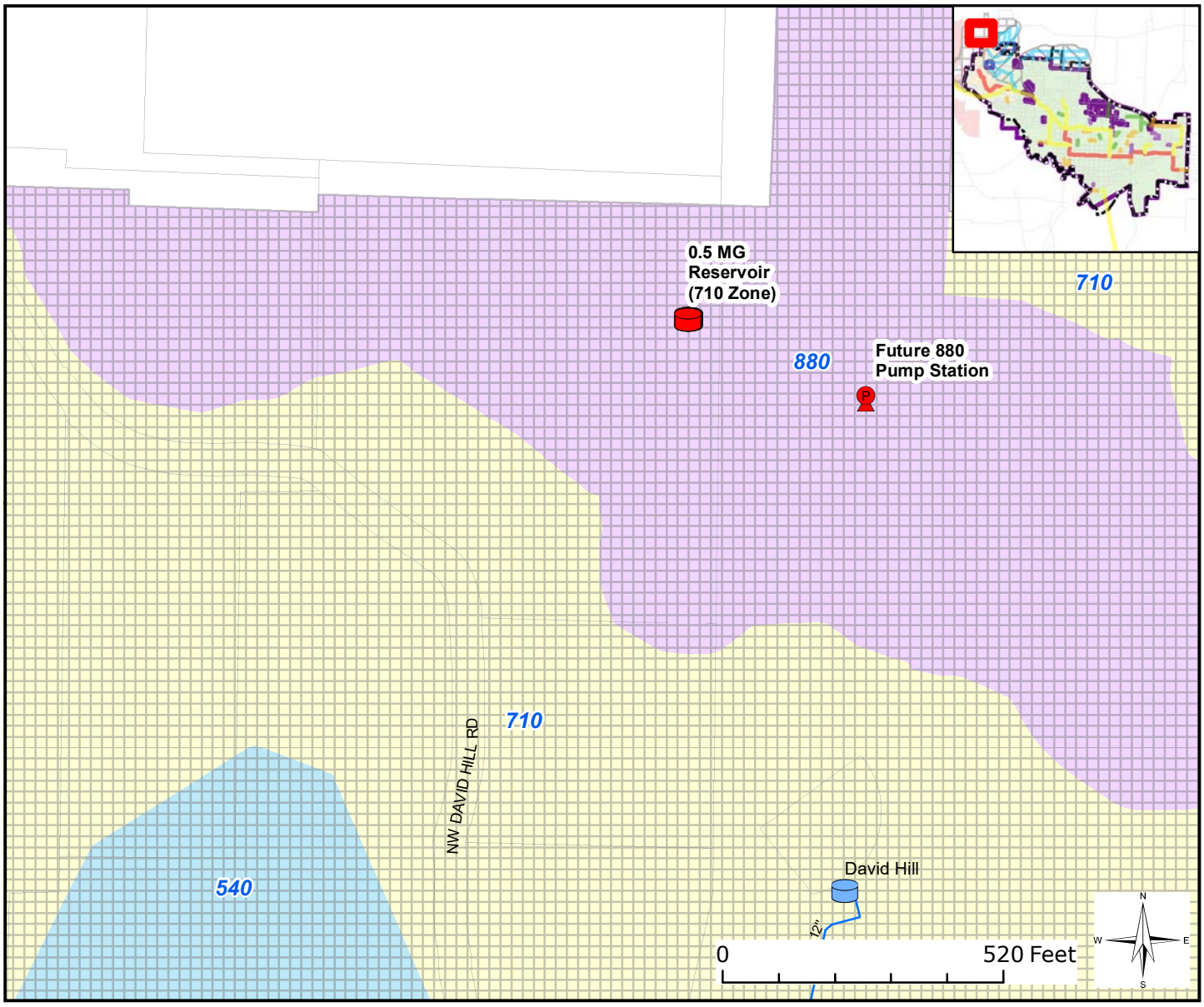


CIP Project R-1

Project Type: Storage
Project Description: Replace existing 5 MG reservoir at City WTP with two 5 MG Reservoirs (10 MG total)
Project Need: Replace aging existing reservoir, provide new storage for future customers, improve facility seismic resilience
Expected Timeframe: 0-5 Years
Priority: High
Project Cost: $22,600,000
Project Phasing: Reservoir 1 within next 5 years, Reservoir 2 likely within next 10 years as development requires

- PumpStation
- PRV
- Tank
- Proposed Pump Station
- Proposed Reservoir
- SRP Improvements
- Future Development w/in UGB
- Transmission Improvements
- 368
- 435
- 540
- David Hill UGB

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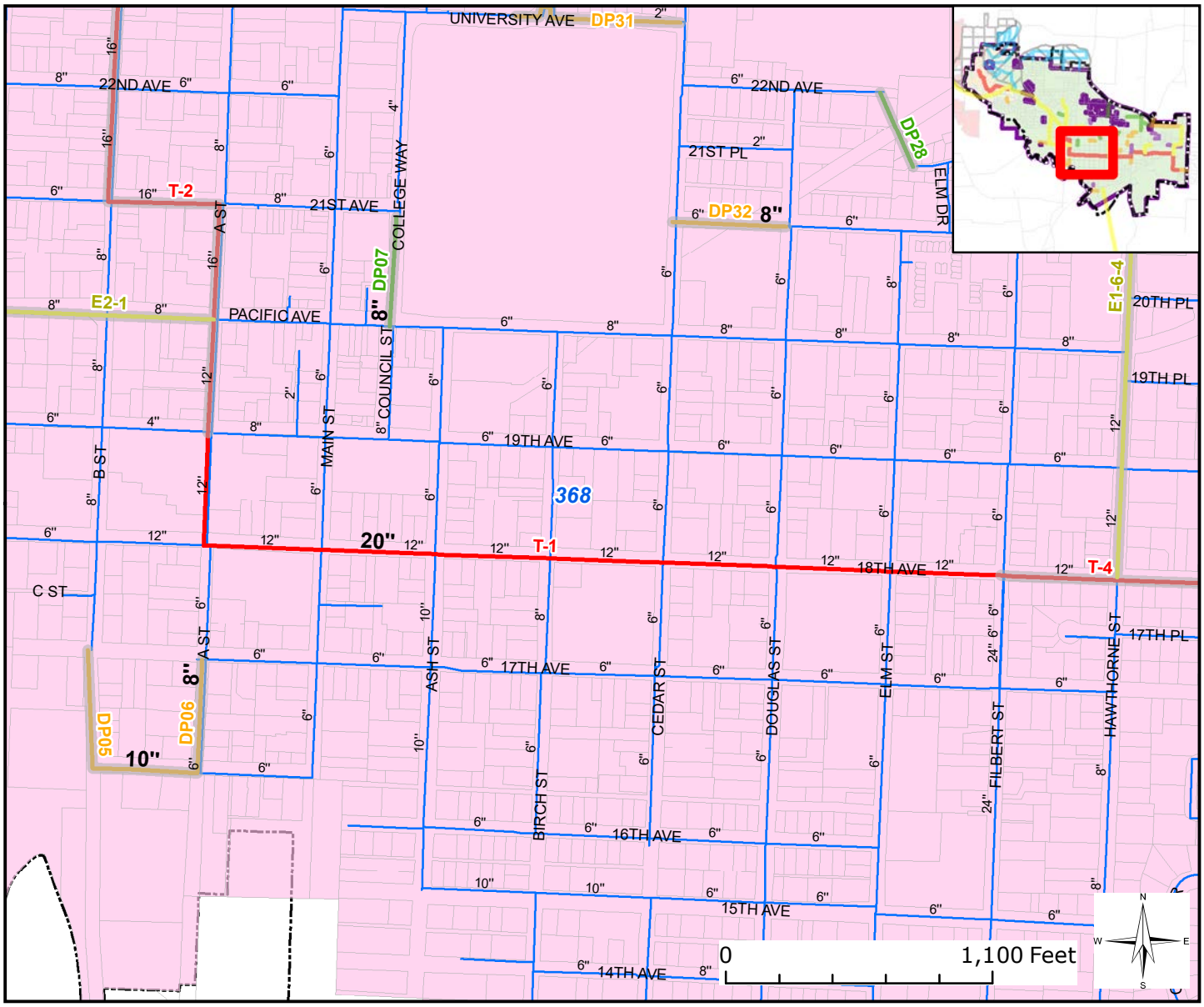


CIP Project R-2

Project Type: Storage
Project Description: New 0.5 MG Reservoir with 710' overflow elevation
Project Need: Storage for new high elevation customers
Expected Timeframe: 11-20 Years
Priority: Medium
Project Cost: $1,000,000
Project Phasing: As development requires

PumpStation
PRV
Tank
Proposed Pump Station
Proposed Reservoir
540
710, Future
880, Future
David Hill URA

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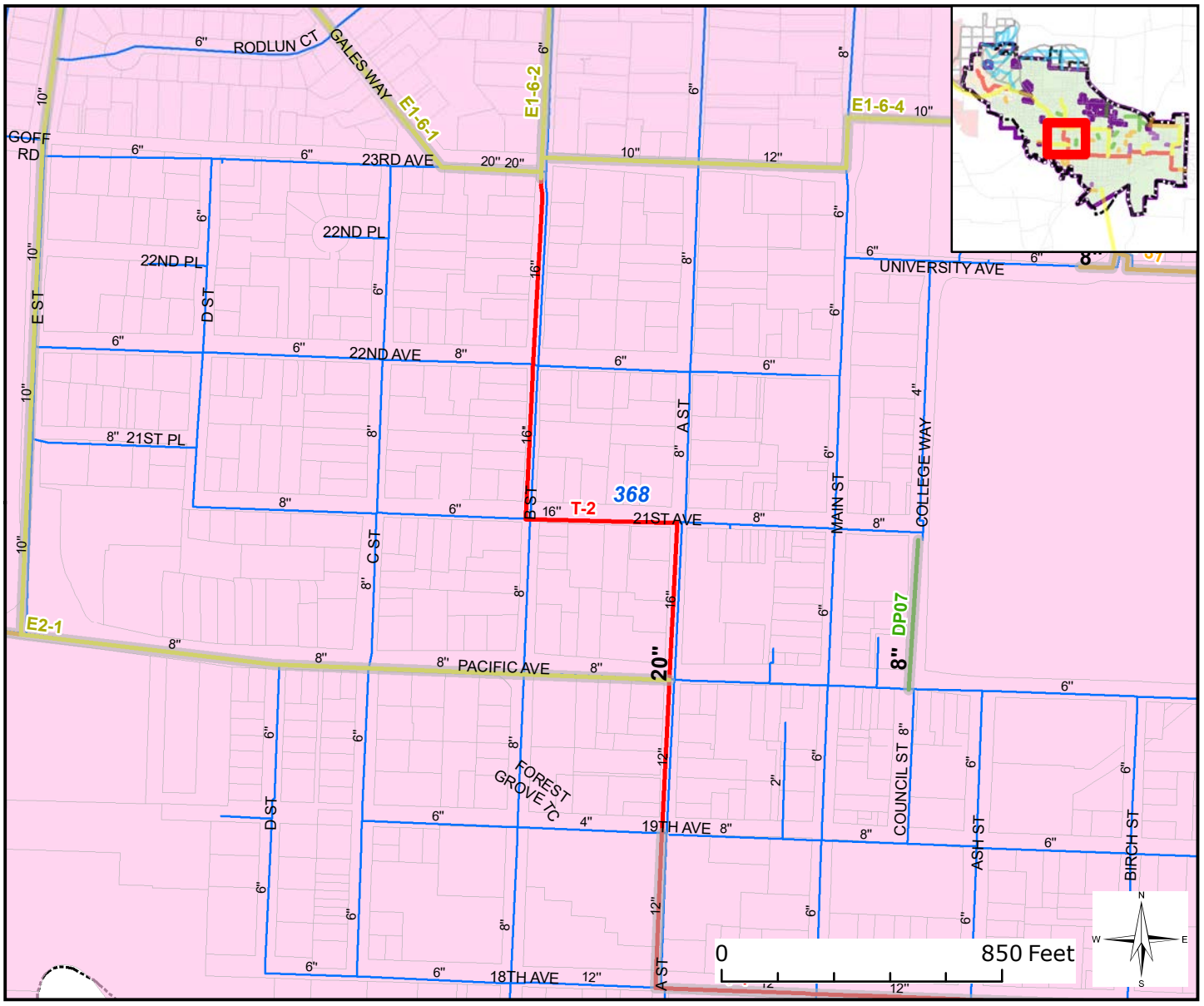


CIP Project T-1

Project Type: Transmission Improvements
Project Description: 10th Ave Transmission, upsize existing 12" transmission from 18th and Filbert St to 23rd and B St, 20"
Project Need: Improve transmission through the center of the FG system - improves supply to/from 5 MG Reservoir, 10th Ave, and Heather St
Expected Timeframe: 0-5 Years
Priority: High
Project Cost: $3,050,000
Project Phasing: First half of 10th Ave transmission upsizing

- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

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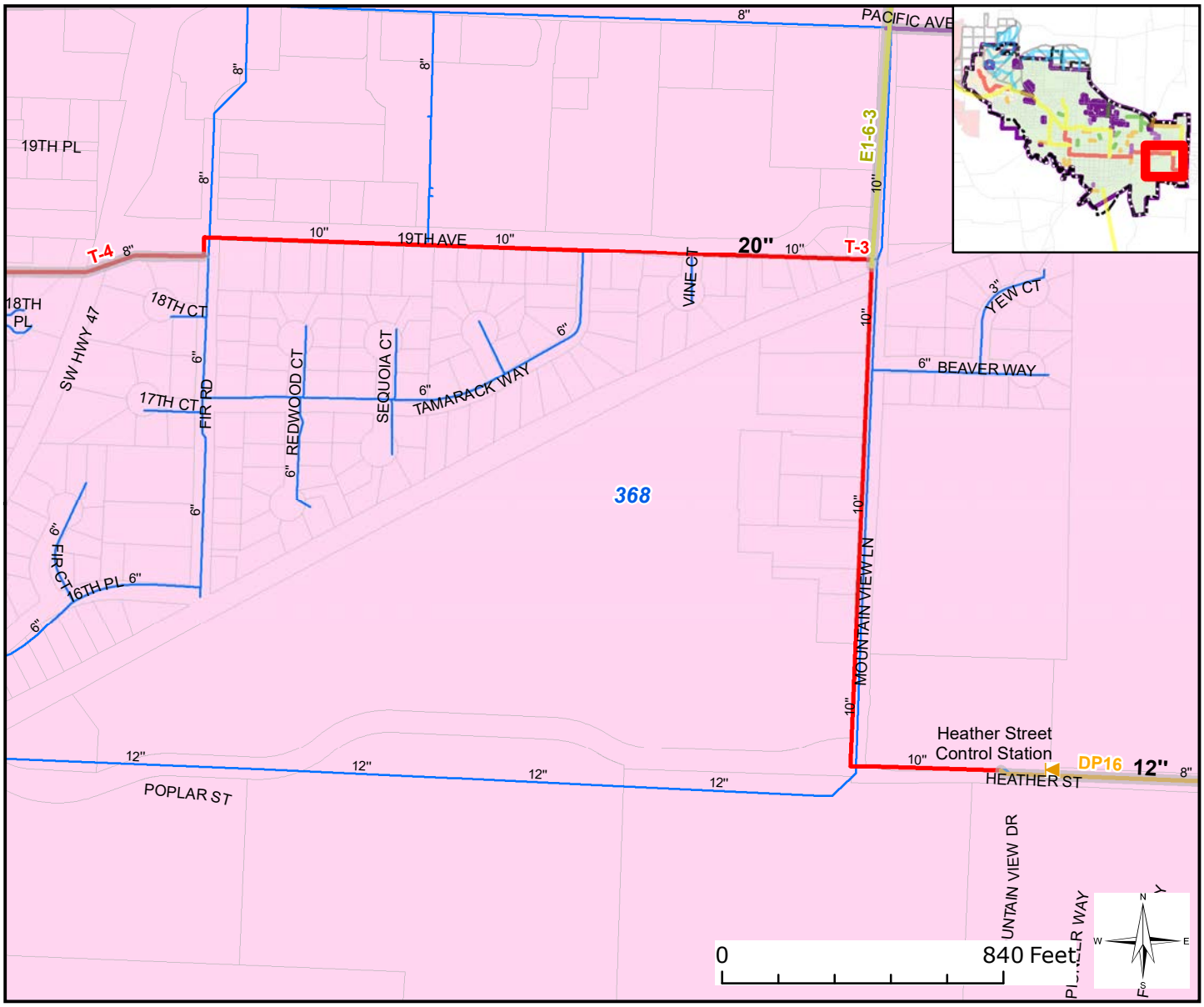


CIP Project T-2

Project Type: Transmission Improvements
Project Description: 10th Ave Transmission, upsize existing 16" from 23rd and B St to Pacific Ave and A St, 20"
Project Need: Improve transmission through the center of the FG system - improves supply to/from 5 MG Reservoir, 10th Ave, and Heather St
Expected Timeframe: 6-10 Years
Priority: Medium
Project Cost: $1,440,000
Project Phasing: Second half of 10th Ave transmission upsizing

- PumpStation
- PRV
- Tank
- SRP Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

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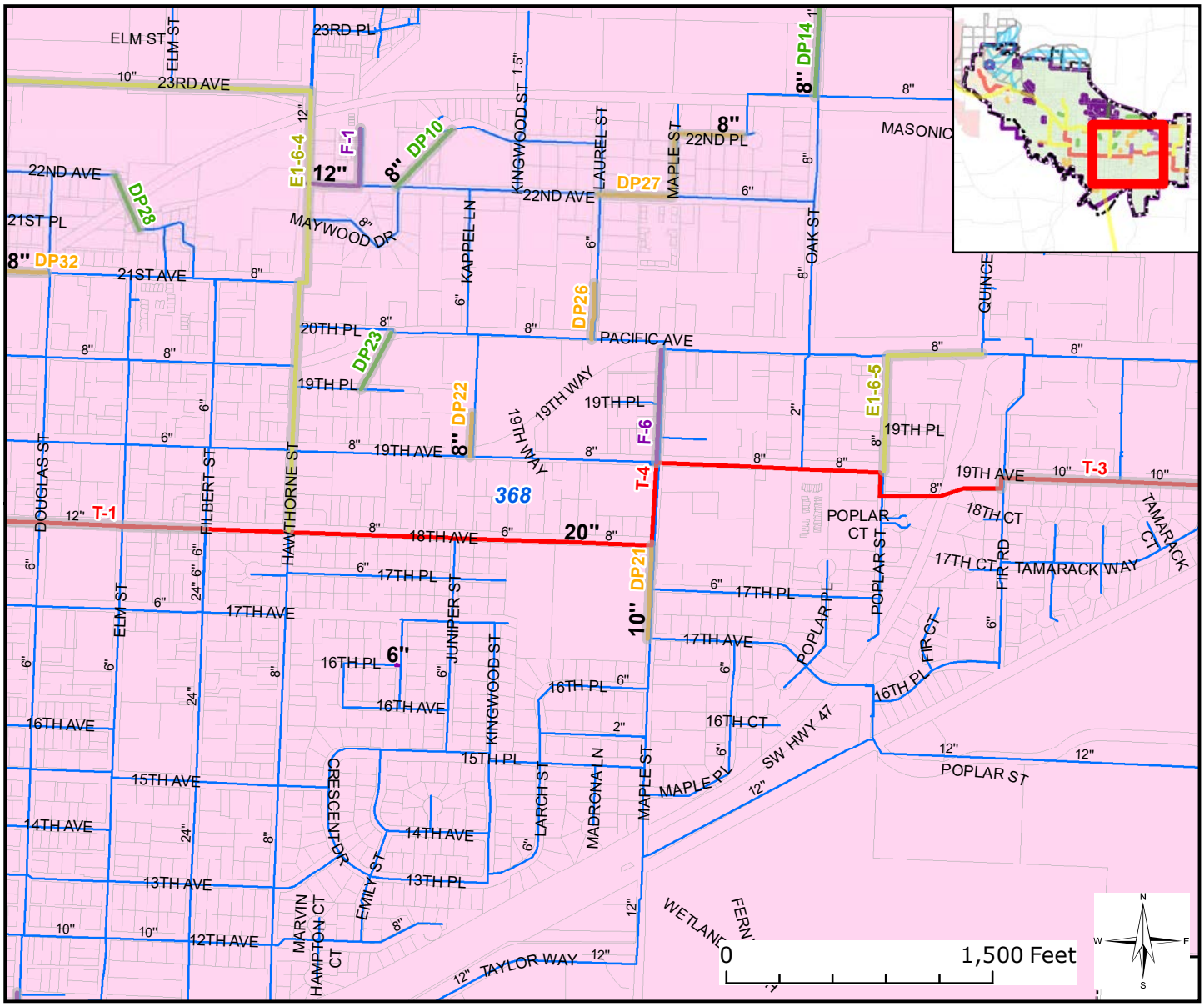


CIP Project T-3

Project Type: Transmission Improvements
Project Description: Heather Ave Transmission, upsize existing 8-10" from Heather Ave Intertie, north to 19th Ave, to TV Hwy crossing, 20"
Project Need: Improve transmission from Heather St to east FG system - improves supply to/from 5 MG Reservoir and JWC supply for both supply and fire flow
Expected Timeframe: 0-5 Years
Priority: High
Project Cost: $2,880,000
Project Phasing: First half of Heather St transmission upsizing

- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368

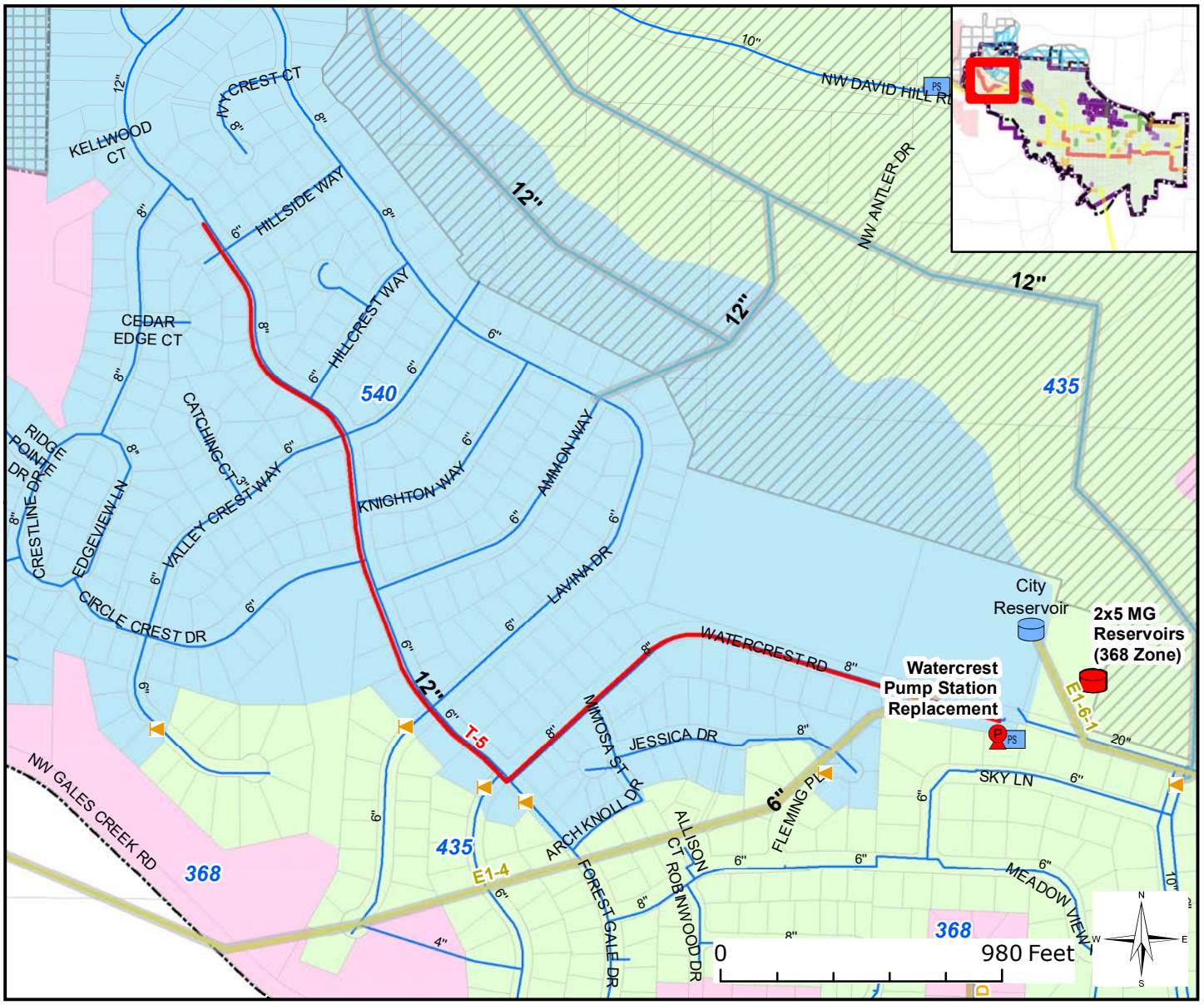
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CIP Project T-4

Project Type: Transmission Improvements
Project Description: Heather Ave Transmission, upsize existing 8" from east of TV Hwy, TV Hwy crossing, to Filbert and 18th Ave, 20"
Project Need: Improve transmission from east FG system to central - improves supply to/from 5 MG Reservoir and Heather St for both supply and fire flow
Expected Timeframe: 6-10 Years
Priority: High
Project Cost: $3,600,000
Project Phasing: Second half of Heather St transmission upsizing

- PumpStation
- PRV
- Tank
- SRP Improvements
- Fire Flow Improvements
- Prior WMP Improvements, Upsize Existing
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368



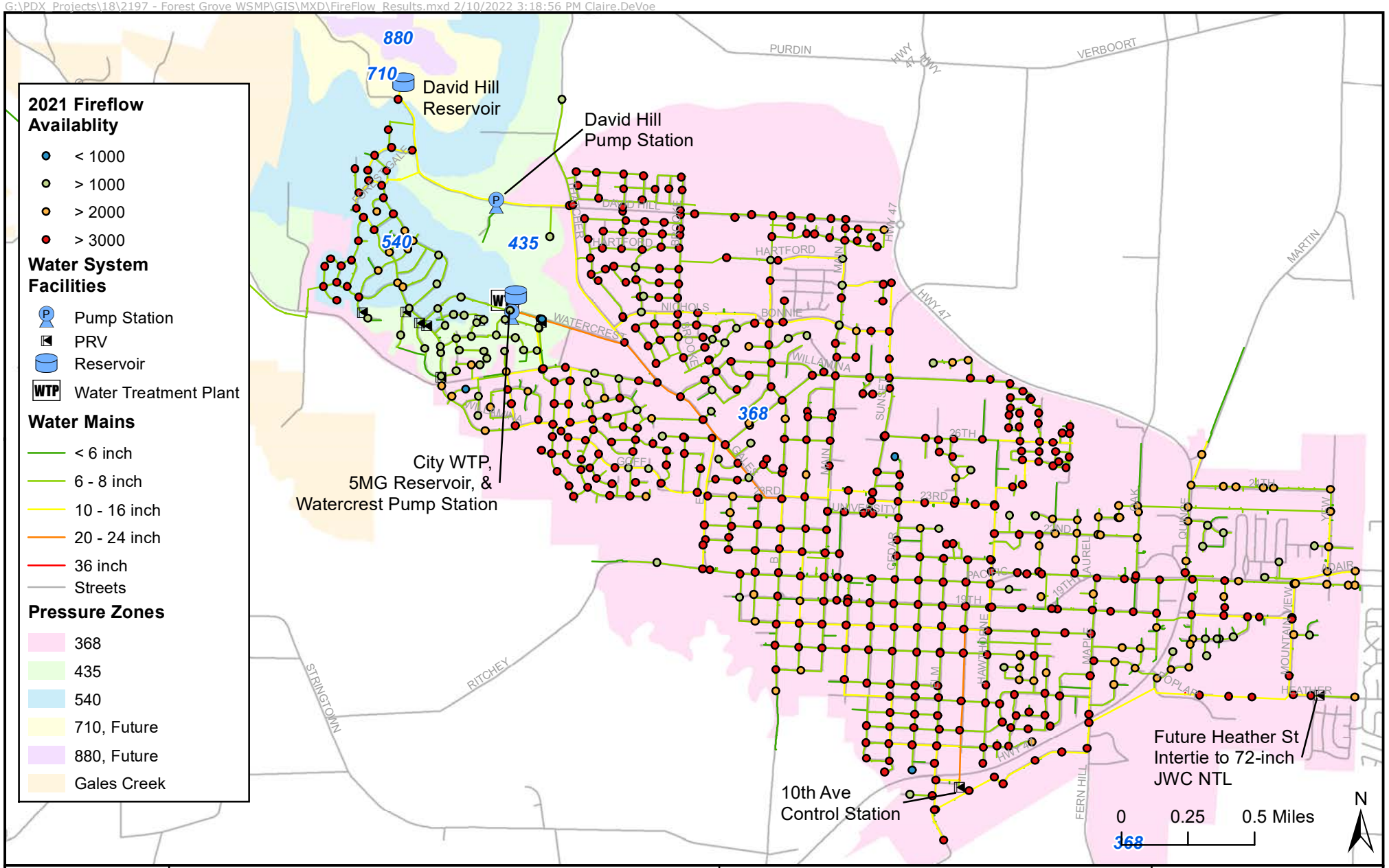
CIP Project T-5

Project Type: Transmission Improvements
Project Description: Transmission from Watercrest Pump Station to Hillside Way along Forest Gale Dr
Project Need: Improve transmission from Watercrest PS to David Hill Reservoir to improve capacity and reliability
Expected Timeframe: 0-5 Years
Priority: Medium
Project Cost: $1,910,000
Project Phasing: Prior to significant upper zone development

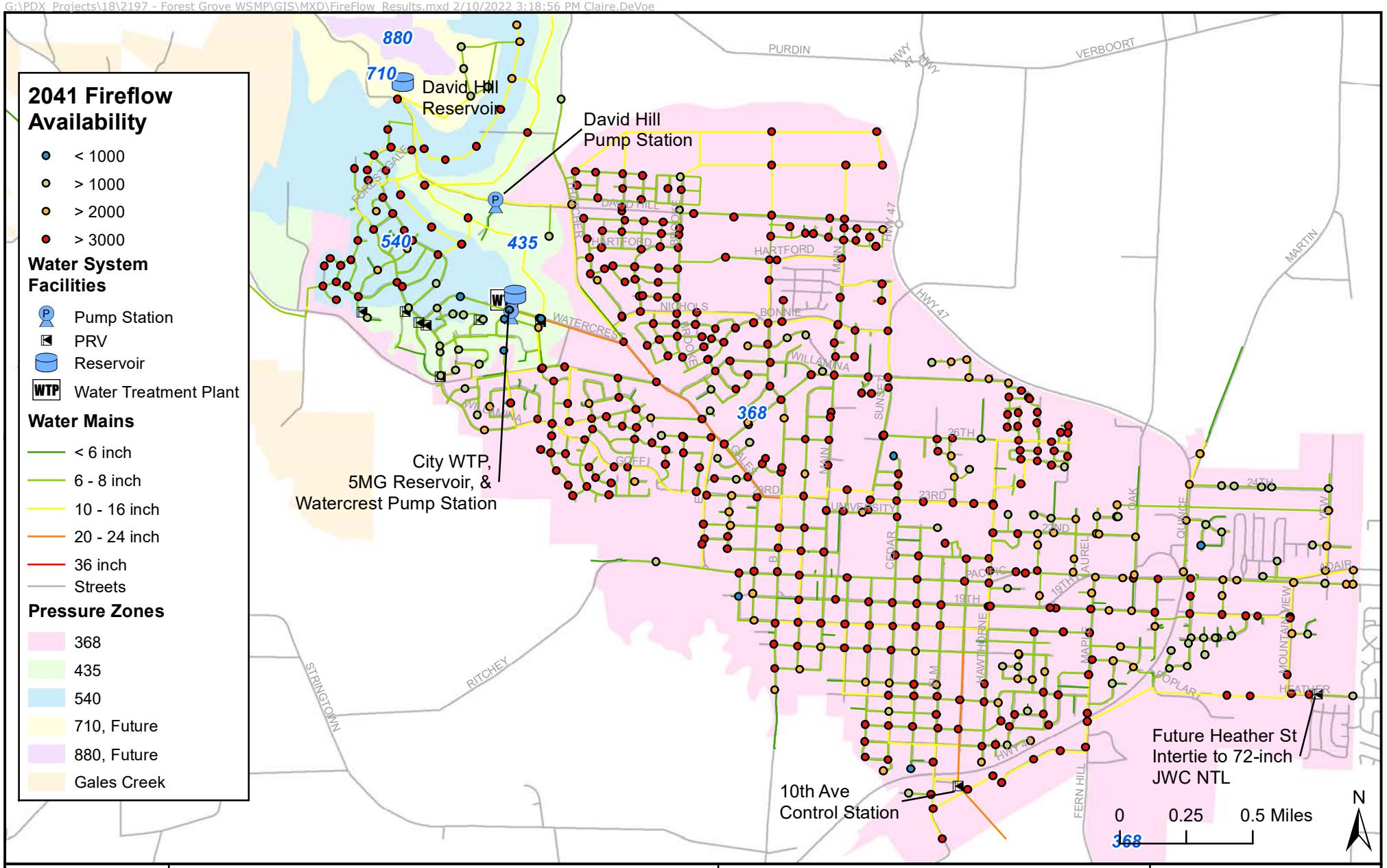
- PumpStation
- PRV
- Tank
- Proposed Pump Station
- Proposed Reservoir
- SRP Improvements
- Future Development w/in UGB
- Prior WMP Improvements, New Piping
- Transmission Improvements
- 368
- 435
- 540
- David Hill URA
- David Hill UGB

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APPENDIX J
AVAILABLE FIRE FLOW MAPS

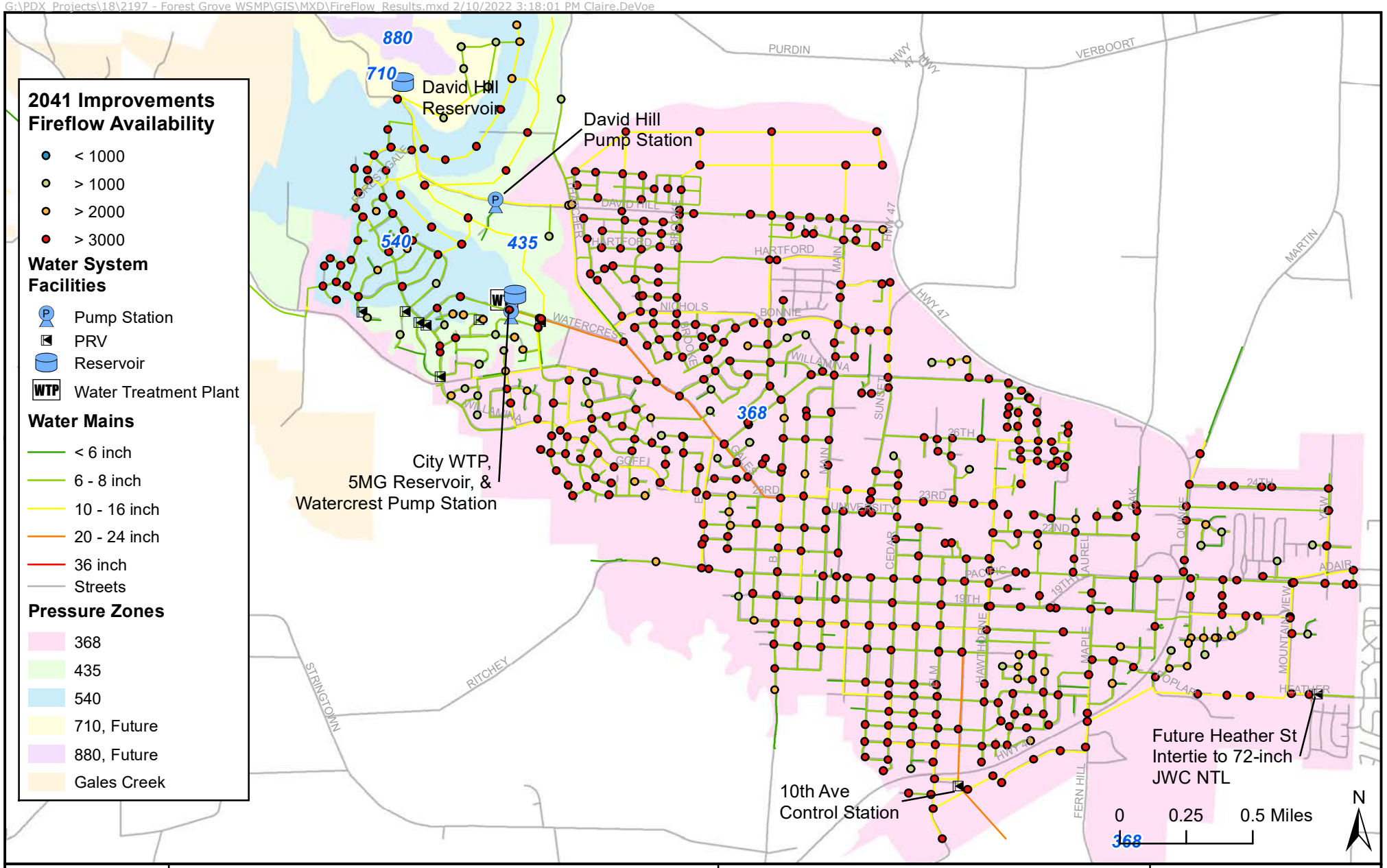


murraysmith	**City of Forest Grove** **Water System Master Plan**	**Figure 1** **2021 Available Fire Flow** **No Improvements**
		FOREST GROVE OREGON 412



murraysmith	**City of Forest Grove** **Water System Master Plan**	**Figure 2** **2041 Available Fire Flow** **No Improvements**

FOREST GROVE OREGON



murraysmith

City of Forest Grove
Water System Master Plan

Figure 3
2041 Available Fire Flow
With Improvements

FOREST GROVE ORE

Figure 4-1
Full Water Rights, Assuming No Seasonal Limitations

Year	2021	2026	2031	2041	2071
Maximum Month Demand (mgd)	5.32	5.73	6.55	7.59	8.66
Clear Creek Certificate (mgd)	1.81	1.81	1.81	1.81	1.81
Clear and Roaring Creek Certificate (mgd)	2.88	2.88	2.88	2.88	2.88
Gales Creek Certificate (mgd)	2.88	2.88	2.88	2.88	2.88
Barney Water Right (mgd)	0.98	0.98	0.98	0.98	0.98
Scoggins Water Right (mgd)	10.79	10.79	10.79	10.79	10.79
Barney Buy-Back (mgd)	1.57	1.57	1.57	1.57	1.57
Tualatin River (mgd)	21.3	21.3	21.3	21.3	21.3

Figure 4-2
Estimated Available Raw Water Supply during Peak Demands

Year	2021	2026	2031	2041	2071
Maximum Month Demand (mgd)	5.32	5.73	6.55	7.59	8.66
Clear Creek Certificate (mgd)	0.52	0.52	0.52	0.52	0.52
Barney Water Right (mgd)	0.98	0.98	0.98	0.98	0.98
Scoggins Water Right (mgd)	10.79	10.79	10.79	10.79	10.79
Barney Buy-Back (mgd)	1.57	1.57	1.57	1.57	1.57
Drought Reduced Stored Water Rights (mgd)	10.67	10.67	10.67	10.67	10.67

Figure 4-5
Finished Water Supply Capacity: Treatment Limitations

Year	2021	2026	2031	2041	2071
Maximum Day Demand (mgd)	6.17	6.64	7.59	8.80	10.03
FG WTP (3.7 mgd)	3.7	3.7	3.7	3.7	3.7
Full JWC Treatment Ownership, less North Plains Demand (mgd)	9.86	9.82	9.76	9.71	9.71

Figure 4-6
Finished Water Supply Capacity: Treatment, Transmission, and Raw Water Supply Limitations

Year	2021	2026	2031	2041	2071
Maximum Day Demand (mgd)	6.17	6.64	7.59	8.80	10.03
Clear Creek Certificate (mgd)	0.52	0.52	0.52	0.52	0.52
JWC 24" TL Capacity (mgd)	6.1	6.1	6.1	6.1	6.1
Additional Supply Assuming Access to Full JWC Treatment Ownership, less North Plains Demand (mgd)	3.76	3.72	3.66	3.61	3.61

Figure 4-3

Estimated Raw Water Availability, Regular Season Limitations

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2021 (mgd)	2.24	2.20	2.50	2.48	3.53	4.17	5.30	5.19	3.72	3.00	2.34	2.51
2026 (mgd)	2.41	2.37	2.69	2.68	3.81	4.50	5.71	5.59	4.01	3.24	2.53	2.70
2031 (mgd)	2.76	2.71	3.08	3.06	4.36	5.15	6.54	6.40	4.58	3.70	2.89	3.09
2041 (mgd)	3.21	3.15	3.58	3.56	5.06	5.98	7.60	7.44	5.33	4.30	3.36	3.59
2071 (mgd)	3.65	3.59	4.08	4.06	5.77	6.82	8.66	8.48	6.07	4.90	3.83	4.09
FG WTP Restricted Water Supply (mgd)	4.69	4.69	4.69	4.69	2.77	2.81	1.70	0.88	0.54	0.54	0.82	4.69
Barney Water Right (mgd)	0	0	0	0	0.16	0.54	0.87	0.98	0.62	0.46	0.47	0
Scoggins Water Right (mgd)	0	0	0	0	1.76	5.95	9.61	10.79	6.88	5.12	5.18	0
Barney Buy-Back (mgd)	0	0	0	0	0.26	0.86	1.40	1.57	1.00	0.74	0.75	0
Tualatin River Seasonally Restricted Supply (mgd)	21.3	21.3	21.3	21.3	10.65	0	0	0	0	0	10.65	21.3

Figure 4-4

Estimated Raw Water Availability, Seasonal and 20% Drought Limitations

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2021 (mgd)	2.24	2.20	2.50	2.48	3.53	4.17	5.30	5.19	3.72	3.00	2.34	2.51
2026 (mgd)	2.41	2.37	2.69	2.68	3.81	4.50	5.71	5.59	4.01	3.24	2.53	2.70
2031 (mgd)	2.76	2.71	3.08	3.06	4.36	5.15	6.54	6.40	4.58	3.70	2.89	3.09
2041 (mgd)	3.21	3.15	3.58	3.56	5.06	5.98	7.60	7.44	5.33	4.30	3.36	3.59
2071 (mgd)	3.65	3.59	4.08	4.06	5.77	6.82	8.66	8.48	6.07	4.90	3.83	4.09
Drought FG WTP Supply (mgd)	3.75	3.75	3.75	3.75	2.22	2.25	1.36	0.70	0.43	0.43	0.65	3.75
Tualatin River Supply (mgd)	17.04	17.04	17.04	17.04	8.52	0	0	0	0	0	8.52	17.04
Impoundments Supply (mgd)	0	0	0	0	1.74	5.89	9.50	10.67	6.80	5.06	5.12	0



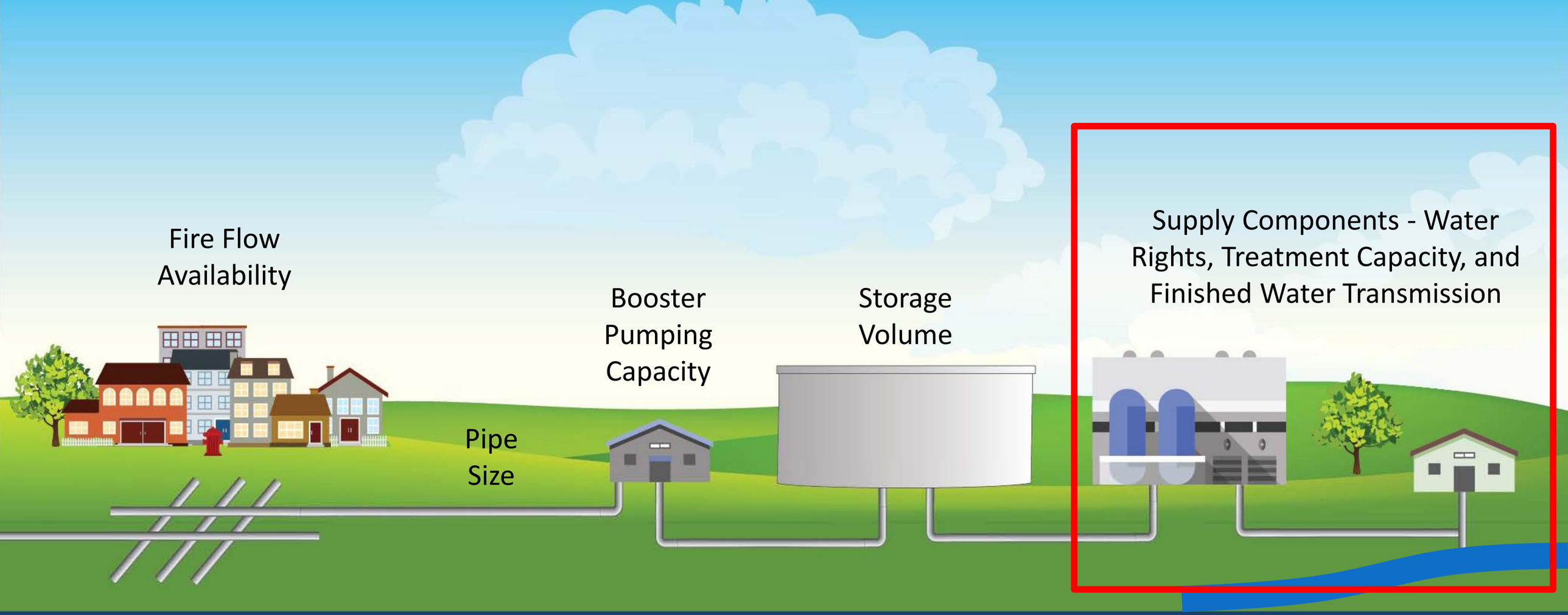
888 SW 5TH AVE, SUITE 1170

PORTLAND, OR 97204

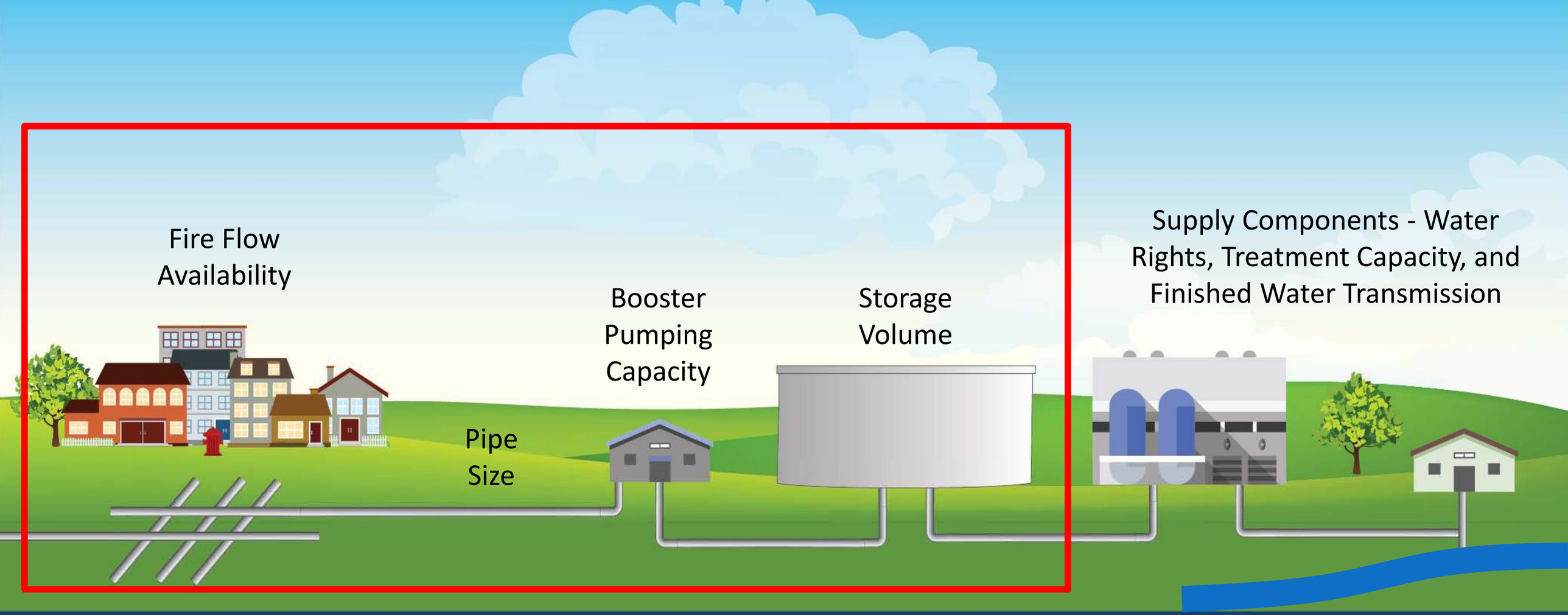
www.murraysmith.us

Purpose of Water System Plan

- Planning Resource for City Staff and Council
- Document System History and Components
- Outline plan for system improvements
- Show financial impact of Capital Improvement Program
- Meet Regulatory Requirements



Water System Components Analyzed



Water System Components Analyzed

Capital Improvement Program Goals



Improve Existing System



Provide for Development



Seismic Preparation



Replace 5 MG Reservoir

Replace aging infrastructure, increase storage capacity, improve seismic resiliency



Increase Transmission of Finished Water from JWC

Increase capacity, improve seismic resiliency



Improve System Transmission

Increase capacity and system resiliency, improve fire flow deficiencies, improve seismic resiliency

Key CIP Projects

Summary

System currently adequately provides for existing residential, commercial, and industrial customers.

Investment is required to provide for future growth.

Additional investment is important to plan for seismic and emergency conditions

The proposed CIP will help the City build a more resilient system.