ES473 Environmental Geology

Field Trip Guide:
Landslide and Flood Hazards of the Monmouth-Independence Area

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Western Oregon University


Eola
Willamette
Minto-Brown Isl
Clow Corner
99W
99W
51
51
Independence Hwy
Independence Hwy
River Rd S
River Rd S
Croisan Creek Rd S
SUNNYSLOP
Davis
Skyline Rd S
Orville Rd S
Cole Rd S
Riverside Dr S
Hoffman Rd
Hoffman Rd
Riddell Rd
N Polk St
N Main St
N 16th St
S 16th St
Talmadge Rd
Pacific Ave N
Independence
Monmouth
194

South

CITY OF Salem AT YOUR SERVICE

TO: Mike Gotterba, CSP, Emergency Preparedness/Communications Manager

FROM: Ken Roley, Facilities Engineering Program Manager
Public Works Department

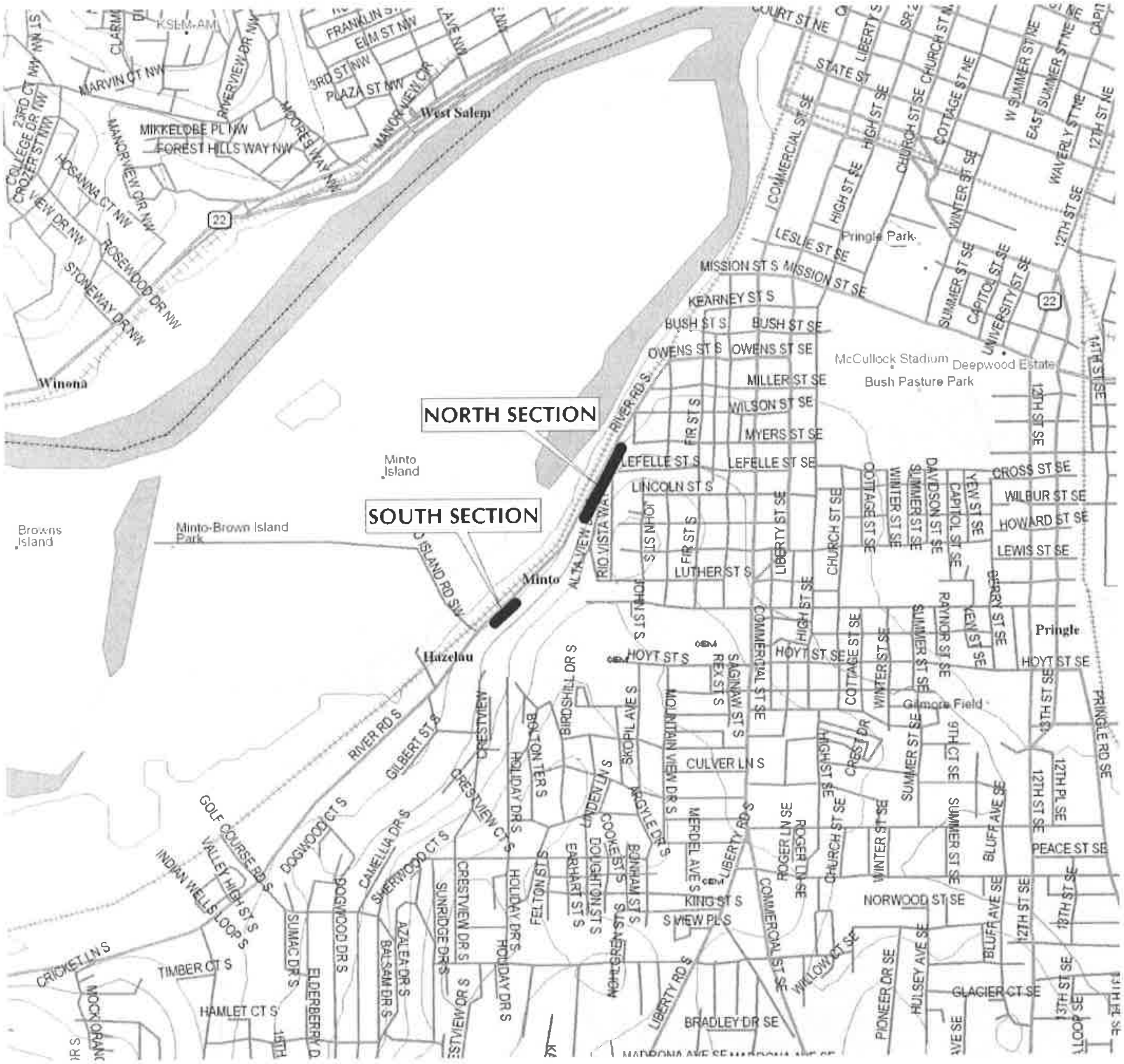
DATE: January 7, 2015

SUBJECT: **History of South River Road Rock Slide Area**

The following is brief history of the rock slide area along S. River Road.

- The area is approximately 1.5 miles southwest of downtown Salem along the western flank of the south Salem hills.
- The area is composed of Columbia River Basalt.
- The slope facing South River road varies from steep (2H:1V) to near-vertical (0.5 H: 1V or steeper)
- The cliffs range from 20 to 70 feet in height.
- The site was investigated by Geotechnical Resources Inc., in 1990 after a series of small slides in the 1980s. A larger slide event occurred on February 8, 1990. This prompted a detailed study by GRI and a follow up construction project.
- The City completed a construction project in 1990 that scaled the slope removing the loose rock, installed screening material, and Jersey barriers with fencing to contain material from small slides.
- This project was not intended to eliminate all future slide events. GRI's report states that "it should be anticipated that these slopes will be subjected to continual surface raveling, block shedding, and topping failures."
- On March 12, 1996 a large slide occurred south of the screened area directly below the home located at 1715 Alta View Dr. S. This prompted a second investigation and a subsequent storm drainage project to divert water from the top of the slope, along Alta View Drive, and from an existing storm drainage pipe at the top of the slide area and carry it to the bottom of the slope. This project was completed in the fall of 1996. This greatly reduced the amount of water going into the slide area and decreased the number of rock slides.
- In 1999 a single rock (approx. 500 lbs.) dislodged near the top of the slope under the screen, 30 to 35 feet up the slope. The screen successfully stopped the rock and held it in place until it could be removed. S. River Road was closed for approx. 6 hours during this event. A scaling team from Roseburg completed the task of removing the large rock.

- On Saturday, January 5, 2002, about 80 cubic yards slid down the hill from a point about 30 feet above the road surface. A crane was brought on site and removes the remaining loose rock and vegetation from the slope.
- January 14-16, 2002, an emergency contract was issued to PKO, Inc. to install 9,000 square feet of addition wire mesh screen for 123 feet on the south end of the rock fall area. (PN# 070023)
- On March 12, 2008, a rock slide occurred closing the north bound lane.
- In March, 2010, several rock slides occurred on the north end of the rock slide area.
- In January, 2011, an additional 9,000 sq. ft. of wire mesh screening was installed on the north end of the slide area. (PN #834001) Total construction cost approximately $33,000.
- In January 20, 2011, an 8 foot diameter rock dislodged near the south end of the rock slide area destroying the rock containment barrier and stopping in the south bound lane. A contractor had to be brought in to break up the rock so it could be hauled away. Several trees were also removed from the top of the slope. Total cost- $18,478.
- June 30, 2011. Final report issued, Long Term Mitigation Alternatives, South River Road Rock Cut Slopes, Salem, Oregon, by Geotechnical Resources, Inc. (GRI).
- On December 4, 2012, rock slide closed the north bound lane.
- On March 25, 2014, closed North River Road so contractor could make repairs on the wire mesh screening system.
- On December 16, 2014, rock slide occurred near the center of the area. Total rock volume was 400 yds^3 and caused extensive damage to the wire mesh screening system. A roll over car accident occurred at the site.
- Minor rock falls continue to occur and can be expected in the future as the basalt rock is exposed and continues to degrade. Many times these types of events do not result in a road closure and the rock is cleaned out from behind the Jersey barriers as needed. This occurs on an annual basis. The wire mesh screens and containment barriers are effective in keeping small amounts of rock contained and off the roadway.
- The area where the screening is placed is periodically sprayed for brush control by Marion County. Our geotechnical consultant has recommended that we limit woody plant growth on the exposed face. Roots from the wood material penetrate into the cracks and fissures between the rocks and tend to encourage "popouts".
- Based on maintenance records from FY 2004/05 to date, Streets has cleaned debris along this slide zone 20 times for an average of 1.8 times per year. The average amount of material removed each year is 30 to 100 cubic yards.



DELORME 3-D TOPOQUADS, OREGON
SALEM WEST, OREG. (4bb, & 4bc) 2004

North

0 1/2 1 MILE

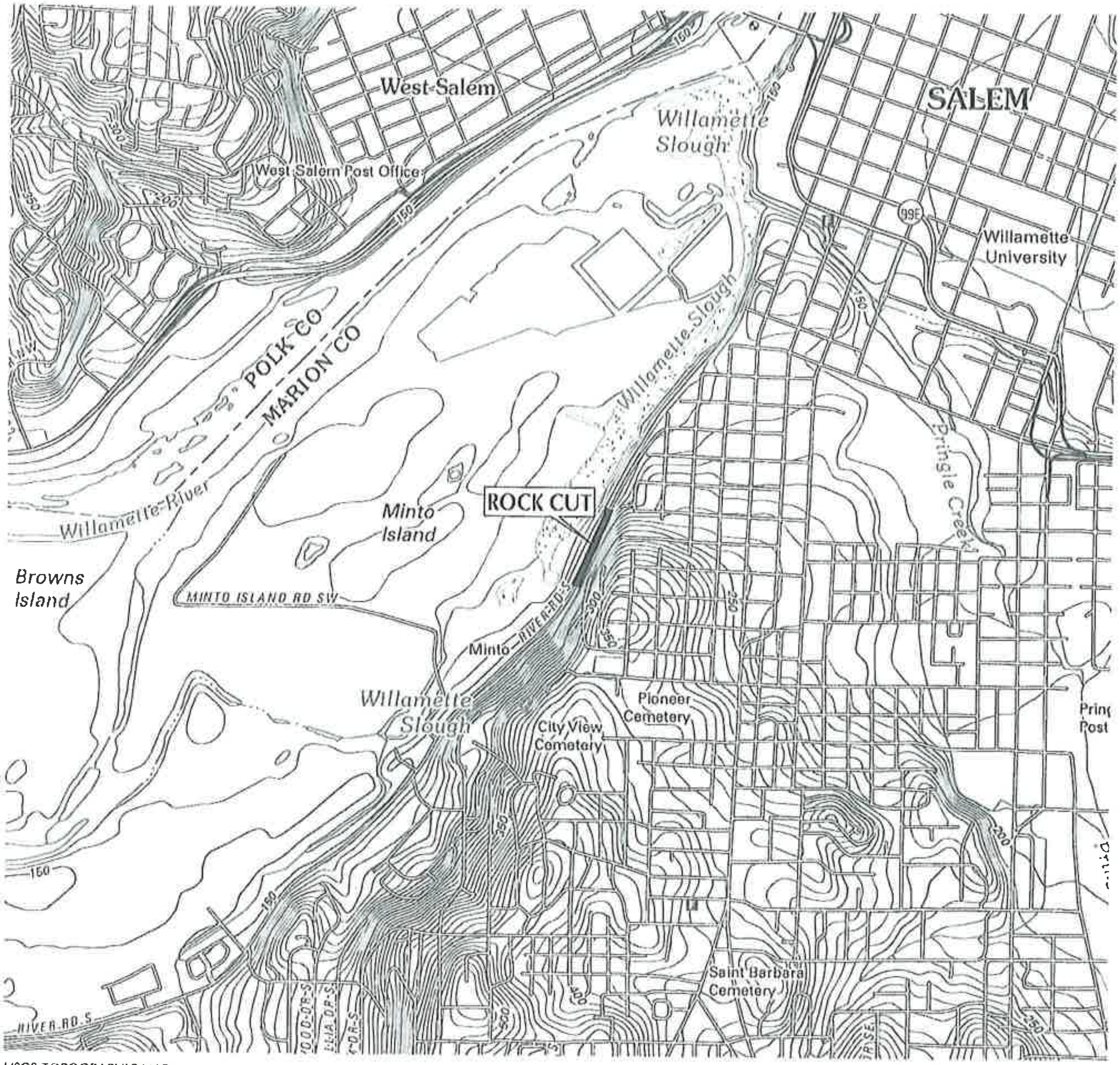
GRI

CITY OF SALEM
S. RIVER ROAD ROCK CUTS

VICINITY MAP

4

JUNE 2011 JOB NO. 5079 FIG. 1



USGS TOPOGRAPHIC MAP
SALEM WEST, OREG. (2014)

North

0 1/2 1 MILE

GRI

CITY OF SALEM
S. RIVER ROAD ROCK CUT MAINTENANCE

VICINITY MAP

APR. 2015 JOB NO. 5079-B FIG. 1

Table 1

GUIDELINES FOR CLASSIFICATION OF ROCK

RELATIVE ROCK WEATHERING SCALE:

Term	Field Identification
Fresh	Crystals are bright. Discontinuities may show some minor surface staining. No discoloration in rock fabric.
Slightly Weathered	Rock mass is generally fresh. Discontinuities are stained and may contain clay. Some discoloration in rock fabric. Decomposition extends up to 1 in. into rock.
Moderately Weathered	Rock mass is decomposed 50% or less. Significant portions of rock show discoloration and weathering effects. Crystals are dull and show visible chemical alteration. Discontinuities are stained and may contain secondary mineral deposits.
Predominantly Decomposed	Rock mass is more than 50% decomposed. Rock can be excavated with geologist's pick. All discontinuities exhibit secondary mineralization. Complete discoloration of rock fabric. Surface of core is friable and usually pitted due to washing out of highly altered minerals by drilling water.
Decomposed	Rock mass is completely decomposed. Original rock "fabric" may be evident. May be reduced to soil with hand pressure.

RELATIVE ROCK HARDNESS SCALE:

Term	Hardness Designation	Field Identification	Approximate Unconfined Compressive Strength
Extremely Soft	R0	Can be indented with difficulty by thumbnail. May be moldable or friable with finger pressure.	< 100 psi
Very Soft	R1	Crumbles under firm blows with point of a geology pick. Can be peeled by a pocket knife and scratched with fingernail.	100 - 1,000 psi
Soft	R2	Can be peeled by a pocket knife with difficulty. Cannot be scratched with fingernail. Shallow indentation made by firm blow of geology pick.	1,000 - 4,000 psi
Medium Hard	R3	Can be scratched by knife or pick. Specimen can be fractured with a single firm blow of hammer/geology pick.	4,000 - 8,000 psi
Hard	R4	Can be scratched with knife or pick only with difficulty. Several hard hammer blows required to fracture specimen.	8,000 - 16,000 psi
Very Hard	R5	Cannot be scratched by knife or sharp pick. Specimen requires many blows of hammer to fracture or chip. Hammer rebounds after impact.	> 16,000 psi

RQD AND ROCK QUALITY:

Relation of RQD and Rock Quality

RQD (Rock Quality Designation), %	Description of Rock Quality
0 - 25	Very Poor
25 - 50	Poor
50 - 75	Fair
75 - 90	Good
90 - 100	Excellent

Terminology for Planar Surface

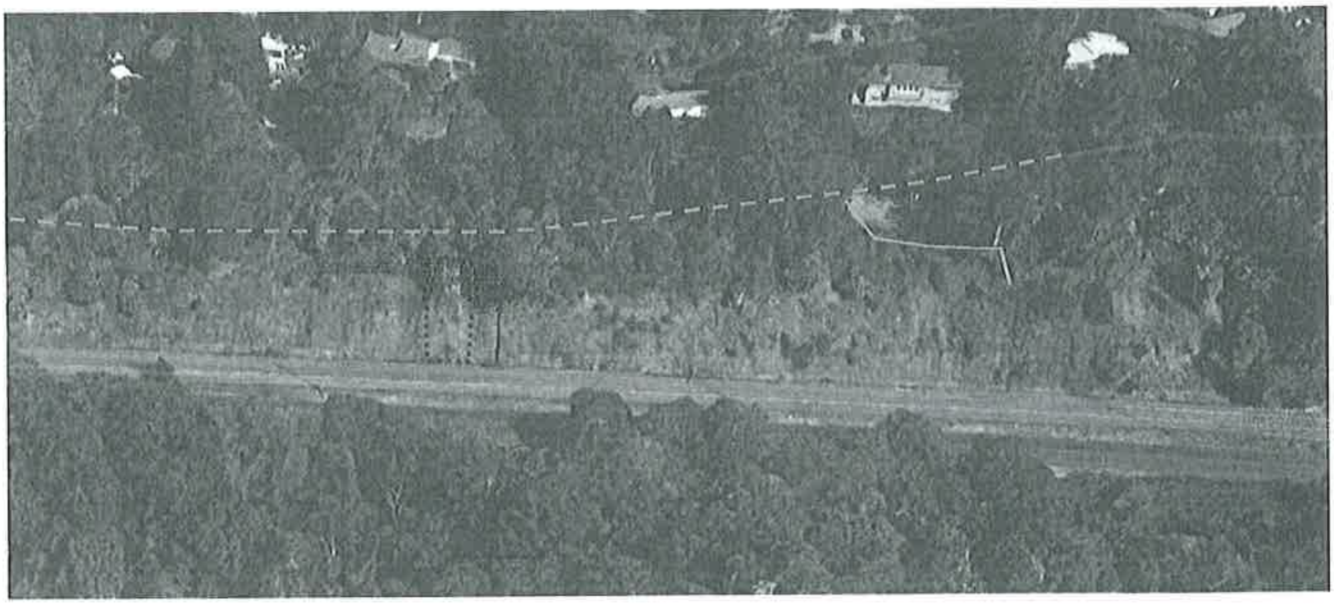
Bedding	Joints and Fractures	Spacing
Laminated	Very Close	< 2 in.
Thin	Close	2 in. – 12 in.
Medium	Moderately Close	12 in. – 36 in.
Thick	Wide	36 in. – 10 ft
Massive	Very Wide	> 10 ft

TABLE 2. ROCKFALL MITIGATION ALTERNATIVES

Mitigation Alternative	Goals Achievable	PRO	CON	Fatal Flaws	Coverage Area for North Cut	Estimated Preliminary Cost [(1)]	Estimated Design Life	Comments
Do Nothing	None	Low capital investment	Risk increasing over time	Project goals unmet	NA	See comment	NA	Total costs include continued maintenance and possible injury or fatality
Rockfall Fence	None	Can stop large debris	Continued rockfall requires cleanup and maintenance Unretained top of cut slope	Deformation across sidewalk and road	1,000 lf	\$800,000 to \$1,500,000	50 years with maintenance	Cost increases with increased size of debris. Preliminary cost of \$1.5M when sized for 8-ft-diameter boulder
Ultrablock Wall / Facing	None	Readily available construction methods and materials	Increased hazard Continued rockfall Unretained top of cut slope Aesthetics	Increased risk	20,000 ft^2 (1,000 lf)	not evaluated due to increased risk	50 to 75 years	Wall height limited due to narrow area for retaining wall footprint Increased rockfall rollout distance results from loss of catchment area
Raise Road	Moderate risk reduction Reduced closures	Readily available construction methods and materials	Unretained top of cut slope Continued rockfall Retaining wall along railroad right-of-way	Extended road closure for construction	1,000 lf	\$2,500,000	> 100 years	Assumes 10-ft grade change Requires roadway grade changes beyond the rock cut limits Requires maintenance to remove accumulated debris
Anchored Mesh	Reduced risk Reduced closures	System flexibility	May require maintenance to remove large rock fragments	None identified	40,000 ft^2 (1,000 lf)	\$1,000,000	50 to 75 years	Requires periodic maintenance to removed vegetation from slope
Soil-Nail Wall	Reduced risk Reduced closures	Structural solution	Expensive Visual impact	None identified	40,000 ft^2 (1,000 lf)	\$5,000,000	75+ years	
Soldier Pile Wall	Reduced risk Reduced closures	Structural solution	Expensive Visual impact Difficult construction	Anchors extend beyond right-of-way	40,000 ft^2 (1,000 lf)	\$5,000,000	75+ years	
Re-grade Cut Slope	Reduced hazard and risk Reduced closures	Long-term solution	Acquiring right-of-way, including residences	Political, none technical	25-ft-wide catchment and 1H:1V (45°) cut slope (1,000 lf)	\$3,000,000+ (see comment)	> 100 years	Costs estimate excludes property acquisition and utility relocation

Note 1: Preliminary cost estimates include construction of the mitigation alternative and exclude costs for design, construction management, contingencies, and peripherals such as sidewalk, roadway paving, and guard rails.

GRI



View looking east; north is to the left. The area of December 2014 rockslide is outlined in red. Areas of rock excavation and slope grading are highlighted yellow. Approximate sewer alignment north of Alta View Drive S is shown in green. The south limit of tree clearing is shown in orange.

GRI CITY OF SALEM
S. RIVER ROAD ROCK CUT MAINTENANCE

OBLIQUE AERIAL VIEW OF ROCK CUT

APR. 2015 JOB NO. 5049-B FIG. 2

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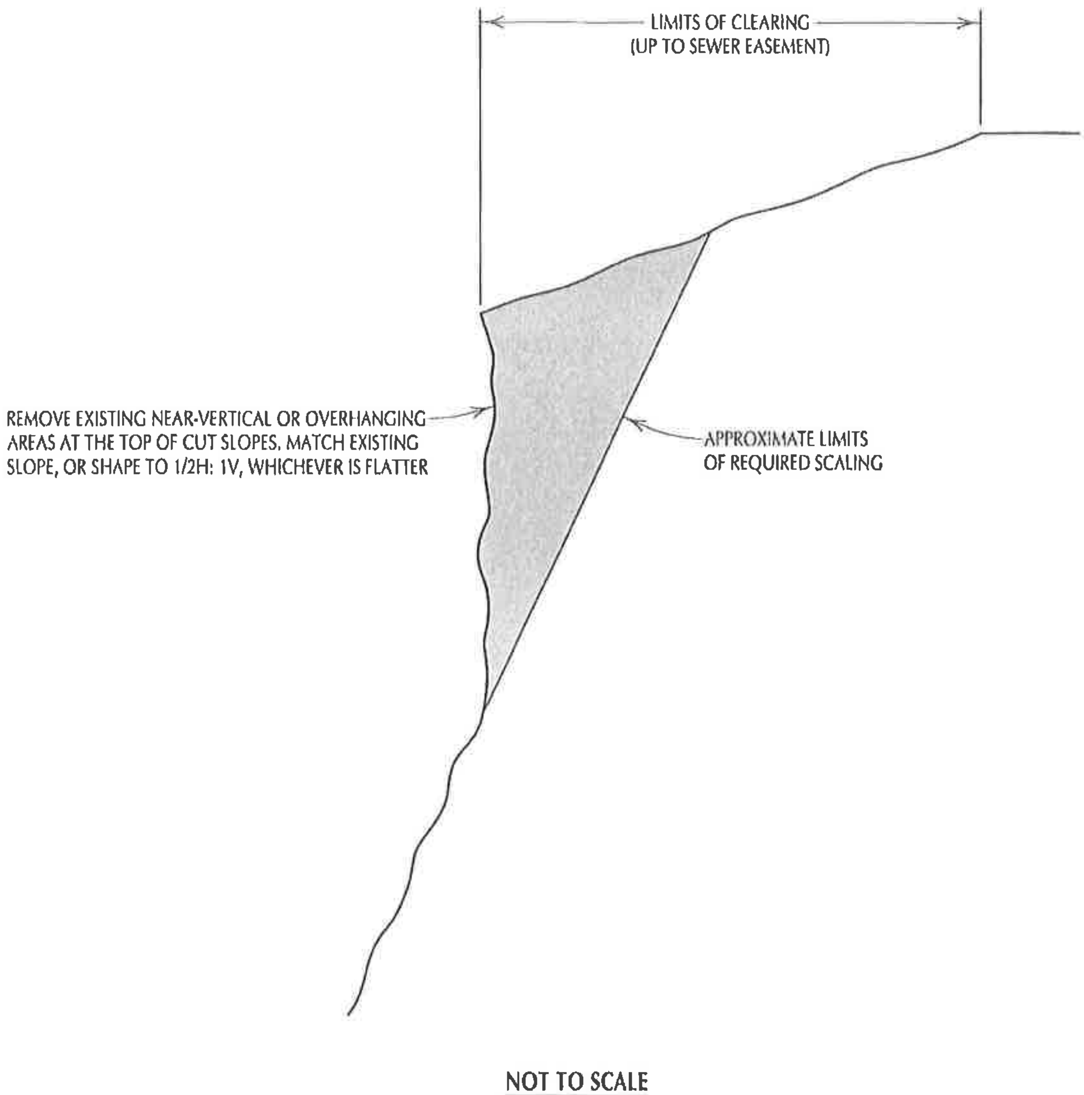
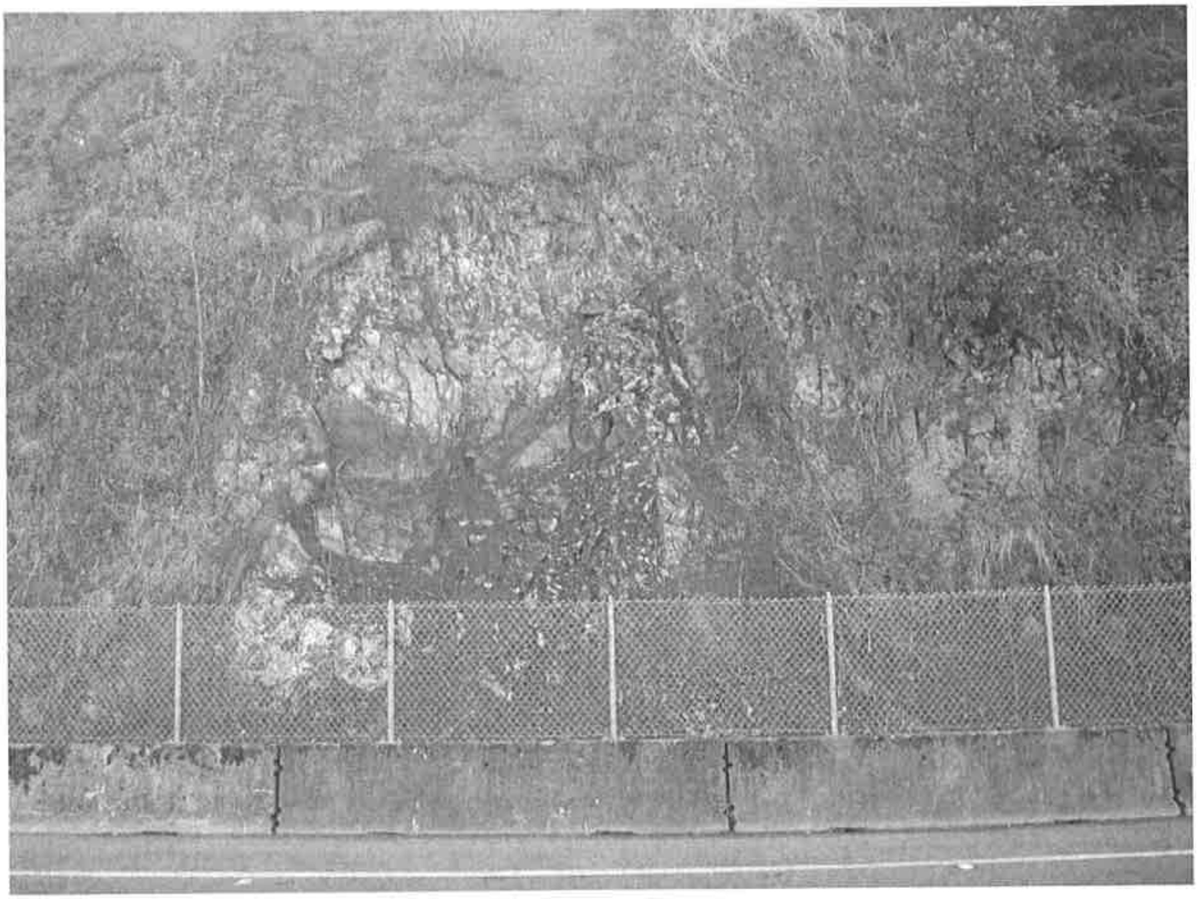


GRI

CITY OF SALEM
S. RIVER ROAD ROCK CUT MAINTENANCE

TYPICAL LIMITS OF CLEARING AND SCALING IN OVERHANGING AREAS

APR. 2015 JOB NO. 5079-B FIG. 3



Scarp from slope failure in March 2011 on south rock cut. The failure is attributable to root wedging in fractures from a tree of similar size to the one shown in the upper right corner of this photograph. (Photograph taken April 8, 2011)

Top of photograph is the uphill direction. Note the open ground crack within the dashed outline of the area above and to the right of the anchor. The top rope for the draped mesh system is located beneath the mesh in this photograph, visible between the arrows to the right of the anchor.

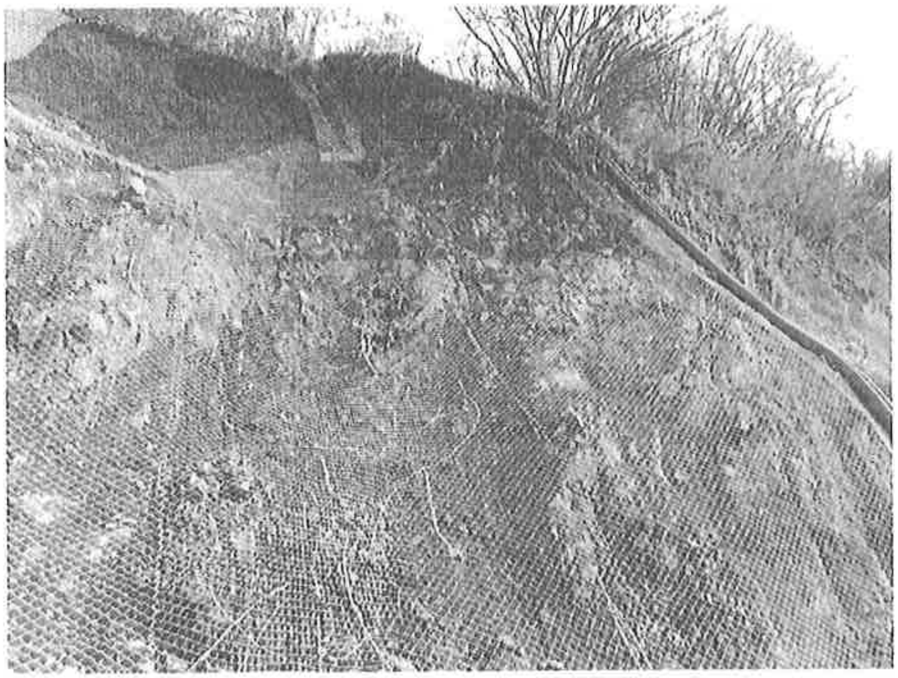
Rock anchor and top of draped mesh in area south of the 2014 rockslide.

Area to remove by rock excavation is highlighted in orange (estimated 50 to 60 cu yd). South end of area to trim back headscarp and overhanging slope is highlighted in green (estimated 1 to 1.5 cu yd per linear ft of rock cut.)

South half of 2014 rockslide, looking southeast.

GRI

11



Area to remove by rock excavation is highlighted in orange. South end of area to trim back headscarp and overhanging slope is highlighted in green.

Same area as above photograph, viewed from a different location.

The area where the overhanging portion at the top of the slope should be trimmed back by mechanical scaling is highlighted in yellow.
The area of the December 2014 rockslide is highlighted in red.

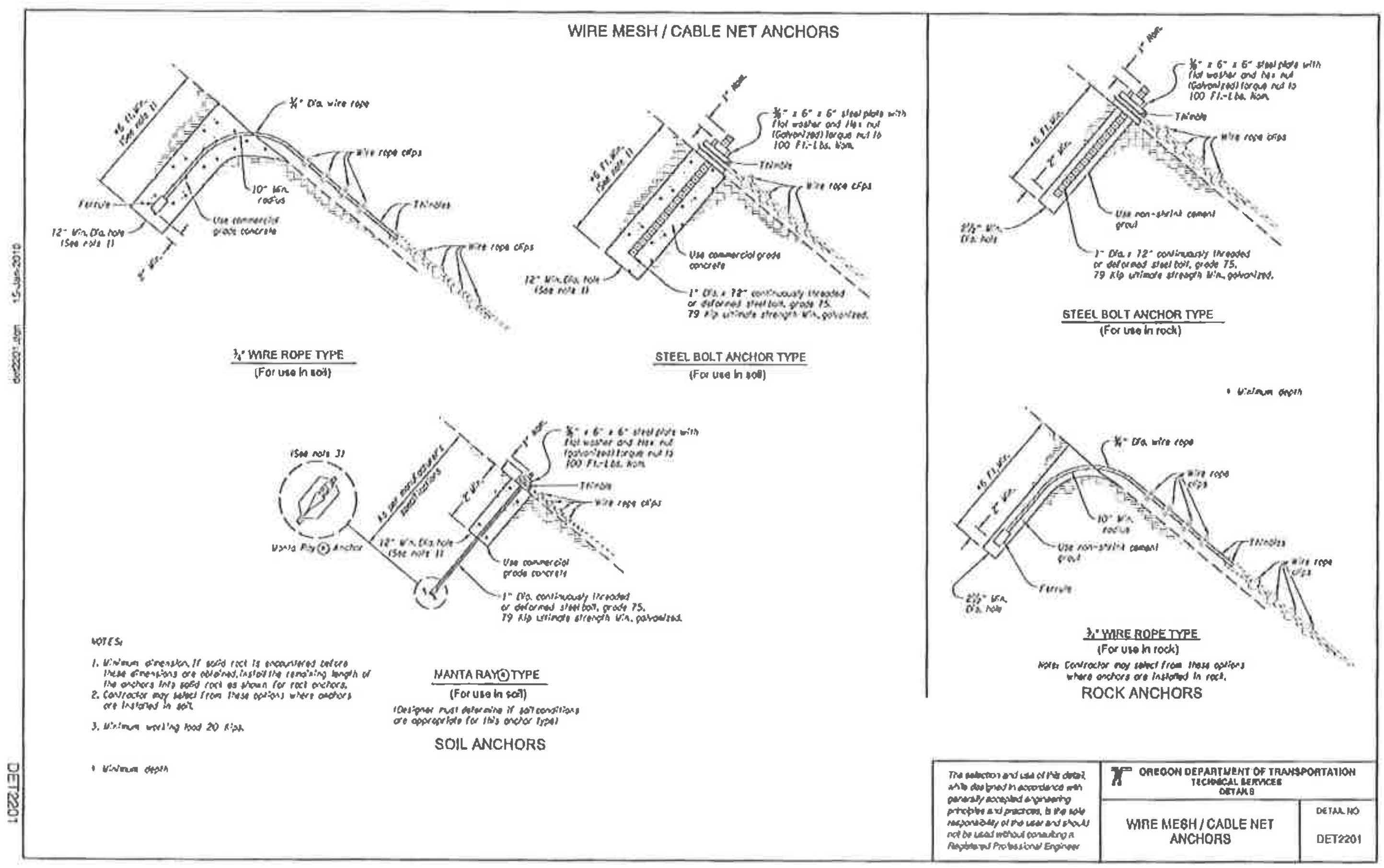
Area to the north of the 2015 rockslide.

GRI

Example of woody vegetation growing through the wire mesh.

Overhanging slope should be trimmed back when the bushes growing through the mesh are removed.

Example of woody vegetation that is growing through the wire mesh.



WIRE MESH / CABLE NET ANCHORS
¾" Dia. wire rope
Wire rope clips
10" Min. radius
Ferrule
Use commercial grade concrete
Thimbles
12" Min. Dia. hole (See note 1)
¾" WIRE ROPE TYPE
(For use in soil)
⅝" x 6" x 6" steel plate with flat washer and Hex nut (Galvanized) torque nut to 100 Ft.-Lbs. Nom.
Thimble
Use commercial grade concrete
1" Dia. x 72" continuously threaded or deformed steel bolt, grade 75. 79 Kip ultimate strength Min., galvanized.
STEEL BOLT ANCHOR TYPE
(For use in soil)
(See note 3)
Manta Ray® Anchor
1" Dia. continuously threaded or deformed steel bolt, grade 75. 79 Kip ultimate strength Min., galvanized.
NOTES:
1. Minimum dimension. If solid rock is encountered before these dimensions are obtained, install the remaining length of the anchors into solid rock as shown for rock anchors.
2. Contractor may select from these options where anchors are installed in soil.
3. Minimum working load 20 Kips.
* Minimum depth
MANTA RAY® TYPE
(For use in soil)
(Designer must determine if soil conditions are appropriate for this anchor type)
SOIL ANCHORS
Use non-shrink cement grout
2½" Min. Dia. hole
1" Dia. x 72" continuously threaded or deformed steel bolt, grade 75. 79 Kip ultimate strength Min., galvanized.
STEEL BOLT ANCHOR TYPE
(For use in rock)
* Minimum depth
¾" WIRE ROPE TYPE
(For use in rock)
Note: Contractor may select from these options where anchors are installed in rock.
ROCK ANCHORS
The selection and use of this detail, while designed in accordance with generally accepted engineering principles and practices, is the sole responsibility of the user and should not be used without consulting a Registered Professional Engineer
OREGON DEPARTMENT OF TRANSPORTATION
TECHNICAL SERVICES
DETAILS
WIRE MESH / CABLE NET ANCHORS
DETAIL NO
DET2201
DET2201

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WIRE MESH SLOPE PROTECTION

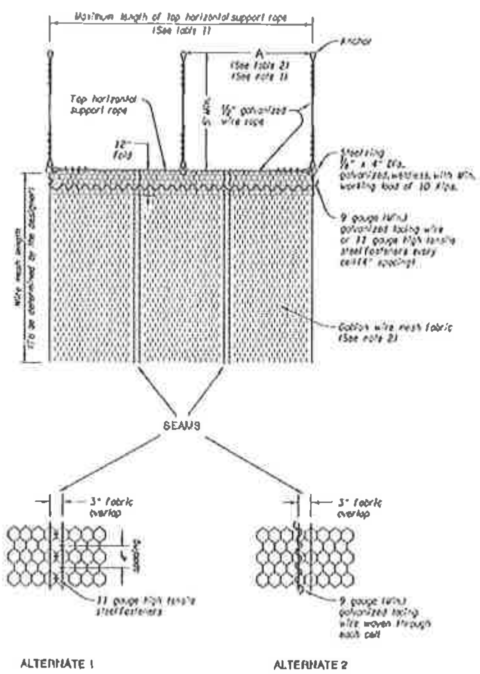
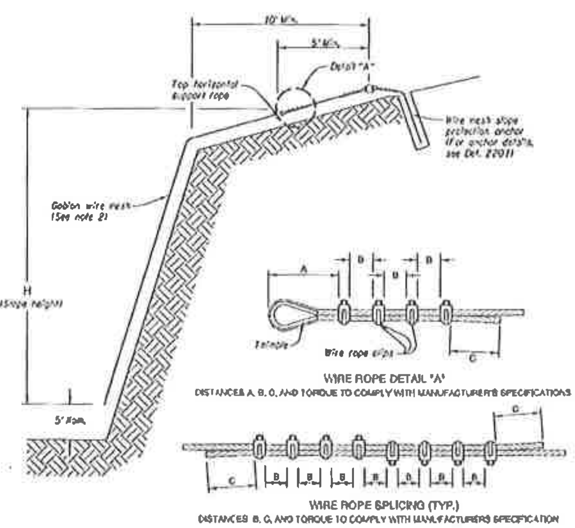


TABLE 1

Maximum length for top horizontal support rope v. slope height for wire mesh	
Slope height H (Ft.)	Max. length for ½" cable fabric weight only (Ft.)
50	333
100	123
200	83
300	43

TABLE 2

MAXIMUM ANCHOR SPACING	
H (Ft.)	A (Ft.)
0 - 100	50
100 - 200	35
200 - 300	20



Notes:

1. To the designer - maximum anchor spacing (A) for debris and impact loads required as per table for a minimum allowable anchor capacity of 20,000 LBF. System subjected to snow loads may require narrower maximum spacing.
2. Designer must select either 11 gauge galvanized or 12 gauge PVC coated gabion wire mesh.

The selection and use of this detail, while designed in accordance with generally accepted engineering principles and practices, is the sole responsibility of the user and should not be used without consulting a Registered Professional Engineer.	OREGON DEPARTMENT OF TRANSPORTATION TECHNICAL SERVICES DETAILS WIRE MESH SLOPE PROTECTION	DETAIL NO DET2203

det2203.dgn 15-Jun-2010

DET2203

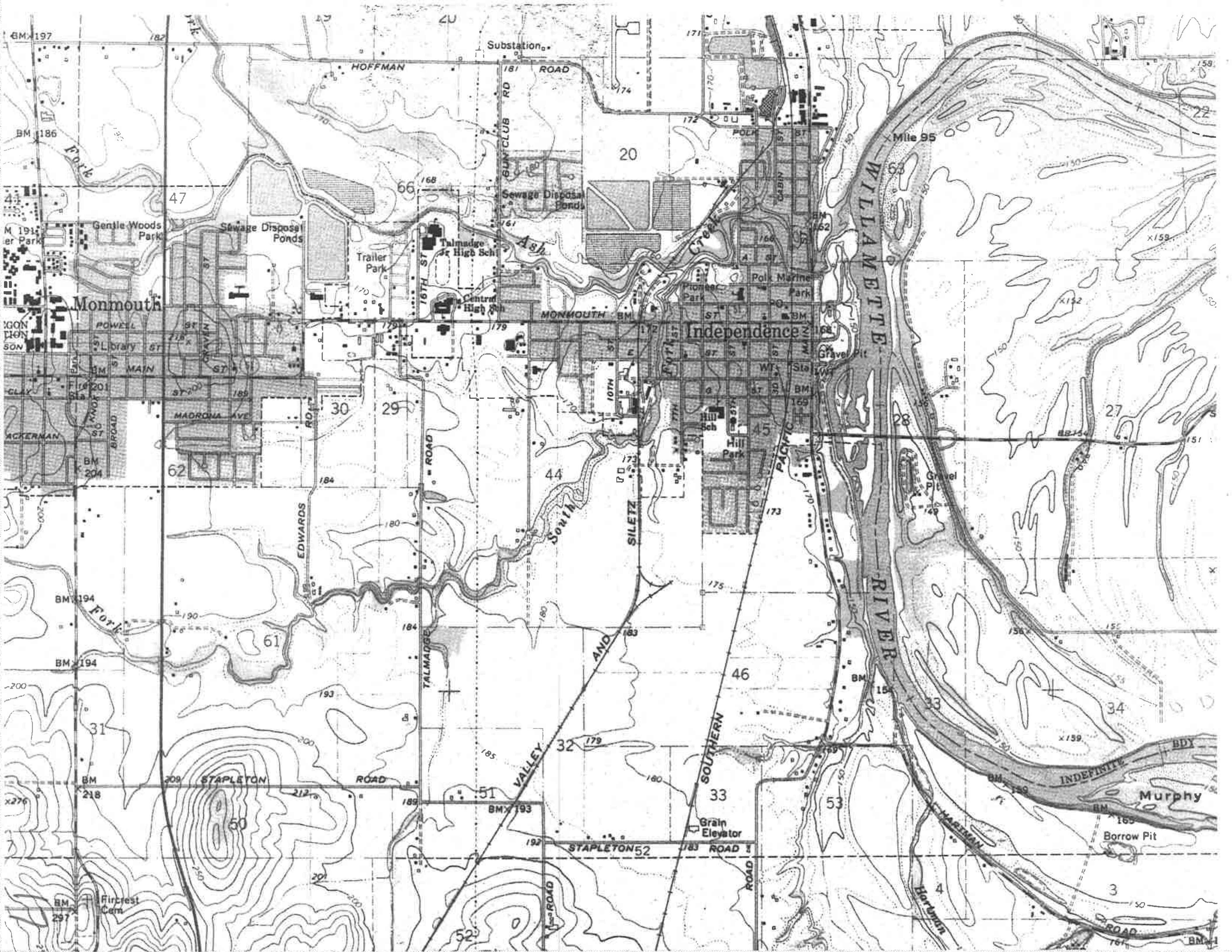
15

Table 1D: Cost Estimate for 2015 "High Priority" Maintenance and Repair Items South River Road, Salem, Oregon

Item	Quantity	Unit Price	Total Amount	Notes
Mobilization	1		$ 18,500	Calculated as 15% of total construction costs
Clearing and Grubbing	5,000 sq ft	$ 2.00	$ 10,000	Includes disposal
Rock Excavation	70 cu yd	$ 250.00	$ 17,500	
Scaling	7,200 sq ft	$ 2.00	$ 14,400	
Wire Mesh	10,000 sq ft	$ 8.00	$ 80,000	120-ft-wide area, includes new anchors
Contingency		25% of Total	$ 30,500	
		Total:	$ 170,900	

Table 2D: Cost Estimate for 2015 "High Priority" and Selected "Moderate Priority" Items as Described in the Text, South River Road, Salem, Oregon

Item	Quantity	Unit Price	Total Amount	Notes
Mobilization	1		$ 33,000	Calculated as 15% of total construction costs
Clearing and Grubbing	25,000 sq ft	$ 2.00	$ 50,000	Includes disposal
Rock Excavation	120 cu yd	$ 250.00	$ 30,000	
Scaling	14,000 sq ft	$ 2.00	$ 28,000	
Wire Mesh	14,000 sq ft	$ 8.00	$ 112,000	170-ft-wide area, includes new anchors
Contingency		25% of Total:	$ 55,000	
		Total:	$ 308,000	


WILLAMETTE
RIVER
Mile 95
Independence
Monmouth
Murphy
INDEFINITE
BDY
Borrow Pit
Gravel Pit
Gravel Pit
Hartman
HARTMAN
SOUTHERN
PACIFIC
AND
VALLEY
SILETZ
Grain Elevator
STAPLETON
ROAD
STAPLETON
ROAD
TALMADGE
ROAD
EDWARDS
RD
HOFFMAN
ROAD
GUN CLUB
RD
Substation
Sewage Disposal Ponds
Sewage Disposal Ponds
Ash
Creek
South
Fork
Fork
Fork
Talmadge Jr High Sch
Central High Sch
Trailer Park
Gentle Woods Park
Hill Sch
Hill Park
Polk Marine Park
Pioneer Park
MONMOUTH
POLK
CABIN
MAIN
MADRONA
AVE
CRAVEN
POWELL
BROAD
KNOX
ACKERMAN
CLAY
Library
16TH ST
10TH
7TH
Fircrest Cem


WILLAMETTE RIVER
Independence
Independence Airport
WALKER ROAD
GILDOW
POLK ST
CABIN ST
MAIN ST
PACIFIC
SOUTHERN
SILETZ
Polk Marine Park
Pioneer Park
Hill Sch
Hill Park
Creek
Fork
Gravel Pit
Gravel Pits
Mile 95
Mile 93
Mile 99
Orville
BURLINGTON
NORTHERN
Rose Lake
SOUTH RIVER ROAD
SALEM HILLS
Vitae Springs
Dickey Res
Cadhorn Spring
INDEFINITE BDY
Murphy Bar
Tyson Island
MARION CO
POLK CO
Borrow Pit
Wigrich Landing
HARTMAN
Grain Elevator
ROAD
50′
T 8 S
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4968
4967
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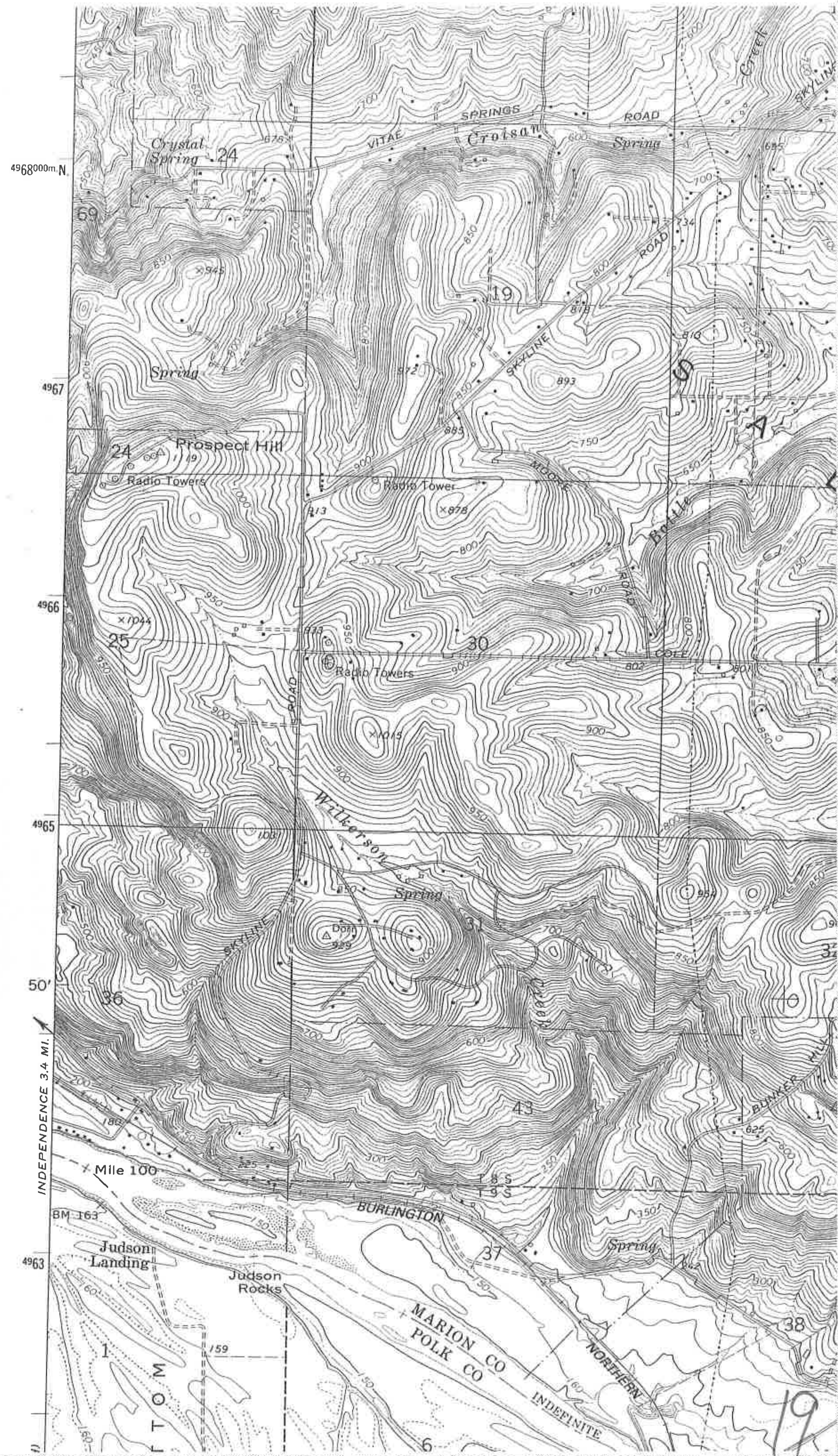
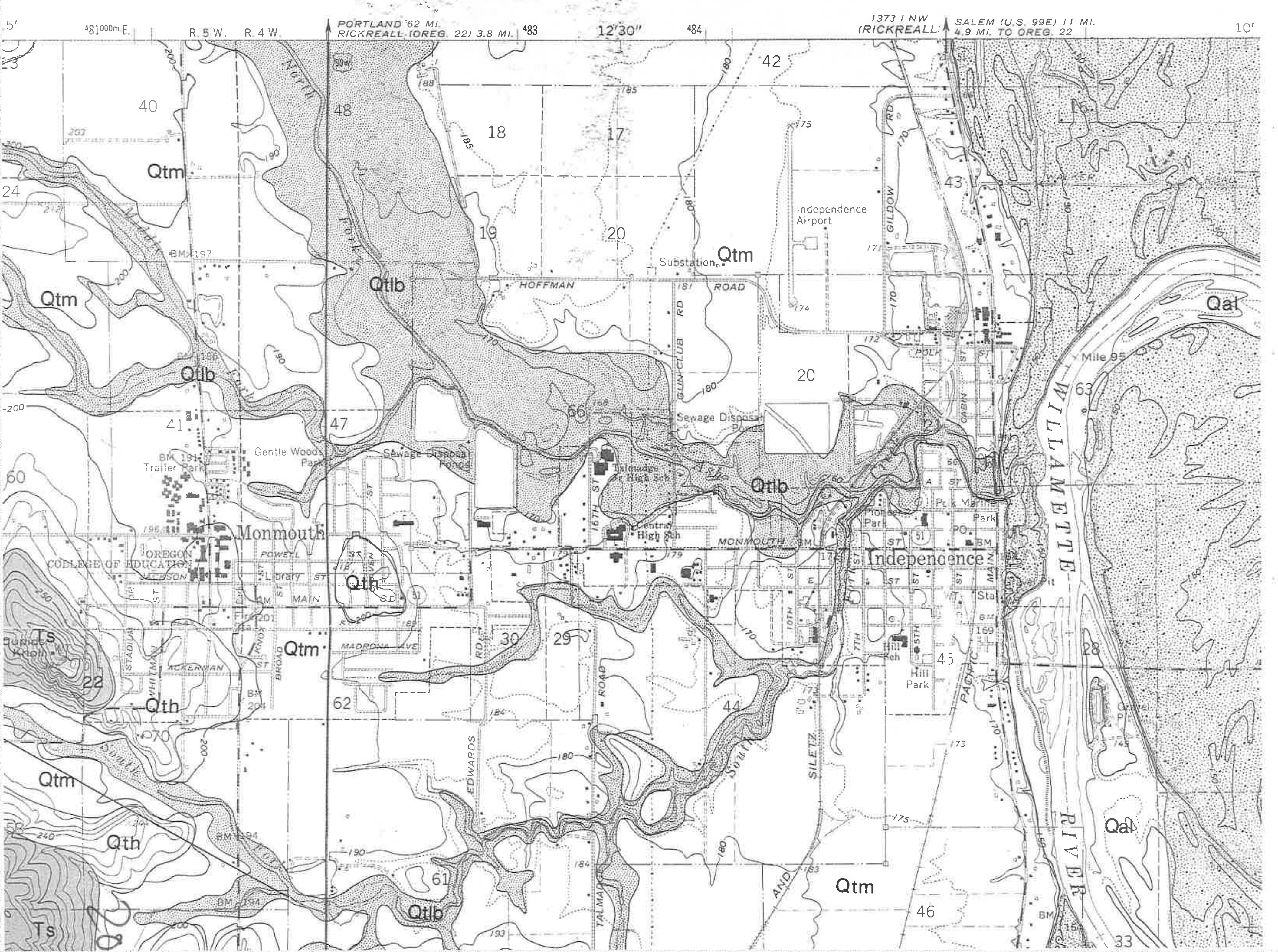
4965
4964



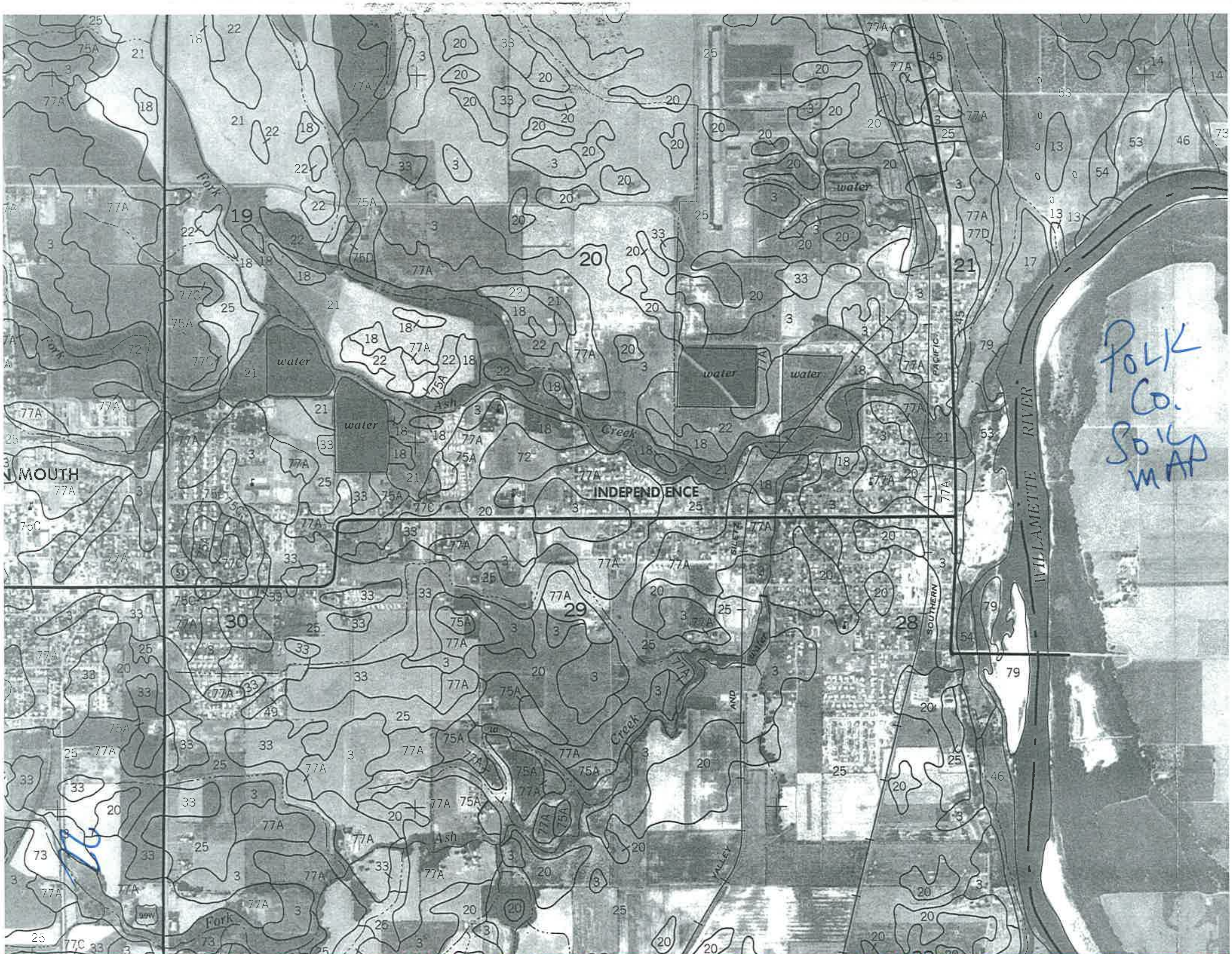
4968000m.N.
4967
4966
4965
50′
4963
VITAE
SPRINGS
ROAD
Croisan
Spring
Creek
SKYLINE
Crystal Spring
24
69
19
Spring
Prospect Hill
Radio Towers
Radio Tower
ROAD
SKYLINE
MOORE
Battle
ROAD
COLE
25
30
Radio Towers
ROAD
Wilkerson
Spring
31
Creek
36
INDEPENDENCE 3.4 MI.
43
BUNKER HILL
Mile 100
T 8 S
T 9 S
BURLINGTON
BM 163
Judson Landing
Judson Rocks
37
Spring
MARION CO
POLK CO
INDEFINITE
NORTHERN
38
1
6
159

19



PORTLAND 62 MI.
RICKREALL (OREG. 22) 3.8 MI.
1373 I NW (RICKREALL)
SALEM (U.S. 99E) 11 MI.
4.9 MI. TO OREG. 22
12'30"
481000m E.
R. 5 W.
R. 4 W.
WILLAMETTE RIVER
Independence
Monmouth
Independence Airport
OREGON COLLEGE OF EDUCATION
Gentle Woods Park
Trailer Park
Talmadge High Sch
Central High Sch
Sewage Disposal Ponds
Substation
Hill Park
Mile 95
HOFFMAN ROAD
GUN CLUB RD
GILDOW RD
MONMOUTH
MADRONA AVE
EDWARDS RD
TALMADGE ROAD
SILETZ AND
PACIFIC
North Fork
South Fork
Qal
Qtm
Qtlb
Qth
Ts

(RICKREALL)
SALEM (U.S. 99E) 11 MI.
4.9 MI. TO OREG. 22
10'
487
1 310 000 FEET
488
SALEM (U.S. 99E) 7 MI.
A
123°07'30"
Qtlw
Qal
Qal
Qtlw
Qal
Qtm
Toe
Tcr
bc
Qtlb
Reichhold-M
(5282')
Prospect
POLK CO
MARION CO
INDEFINITE BDY
WILLAMETTE RIVER
Mile 95
Independence
Independence Airport
GILDOW RD
SILETZ
PACIFIC
Hill Park
Gravel Pit


Polk Co. Soil Map
MOUTH
INDEPENDENCE
WILLAMETTE RIVER
Ash Creek
Fork
water
PACIFIC
SOUTHERN
SILETZ
VALLEY
AND
19
20
21
28
29
30
22

MARION COUNTY SOIL

(Joins lower left)

R. 4 W. NeC

(Joins sheet 51)

1 320 000 FEET

MARION Co. SOIL MAP

Flood Hazards

Why are Floods a Threat to Polk County?

Floods are common events in Oregon and usually fall into one of four categories: flash floods, rain-on-snow floods, snowmelt floods and debris flow floods[1]. Any of these floods can be extremely dangerous and destructive, damaging property and crops and resulting in injury or death. Flood effects may disrupt communities for months and the financial costs of addressing damaged infrastructure can be great.

Floods in Western Oregon have historically occurred during winter months when upper atmosphere winds blow from the southwest. These winds, originating above the Pacific Ocean near the equator, form a "subtropical jet stream" that is a deep and wide mass of warm moist air. Sometimes referred to as the Pineapple Express, the warm air mass will drop above average amounts of rain and melt snow on the west facing slopes of the Cascades Mountains. This combination can create rain-on-snow floods in the Willamette Valley. In fact, this type of event was behind the February 1996 flood that caused severe flooding throughout the Willamette Valley, including Polk County where the Luckiamute River at Suver crested at 33 feet and the Willamette River at Salem crested at 35 feet.[2]

The 1996 floods caused a statewide loss of $400 million in damages, as 26 major rivers rose to flood stage. More than 100 Red Cross and Salvation Army shelters were opened, and 23,000 residents fled their homes. Seven casualties were reported, and 50 people were injured. An estimated 1,700 Oregonians lost their jobs due to flooding, and the Small Business Association (SBA) loaned Oregon businesses over $40.5 million to assist with recovery efforts.[3]

Although this flood was a large-scale disaster, it was not unprecedented. During the Christmas Flood of 1964, over $157 million in damage was done, and 20 Oregonians lost their lives.[4]

Residents in Polk County share a statewide concern about flood issues. According to the National Flood Insurance Program (NFIP), Oregon has 256 flood-prone communities within the 36 counties of the state. Although all of the counties in the state are vulnerable to flooding events, the risk of loss is much more pronounced in some counties than others.

As of September 2002, Oregon had 26,273 NFIP policies with an annual premium total of $11,999,383 – 21.422 for single-family dwellings, 1,023 for two to four-family structures; 1,820 for other residential; and 2,008 for nonresidential. The average premium for all building types was $457. For residential, the average premium was $408 and for nonresidential is $1,051.

History of Flooding in Polk County

The Willamette River basin has a long history of flooding. Many mid-Willamette Valley residents may be familiar with the legendary floods of the 19th Century when the largest flood on record on the Willamette River occurred in 1861. Since then, however, the construction of dams in the 1940s and 1950s changed the pattern of flooding significantly. Polk County has seen two major floods and three lesser floods during the last 35 years. One of the most memorable floods during this time period, the "Christmas" flood of 1964, was rated "approximately a 100 year flood" by FEMA and was probably the most damaging in Oregon's history.[5]

December-January 1964

The "Christmas" flood of 1964 was the largest flood to occur since the major dam construction on the upper Willamette. This flood occurred as a result of two storms, one on December 19, 1964 and the other on January 31, 1965. These storms brought record-breaking rainfall, which exacerbated near record early season snow depths. The flooding caused hundreds of landslides, bridges and roads washed out, houses were damaged or destroyed, and thousands of people were forced to evacuate their homes. Governor Mark Hatfield declared the entire State an emergency disaster area, and called the flooding, "the worst disaster ever to hit the state."[6]

Monetary loss due to sedimentation and other damages to agricultural lands resulting from the 1964 flood amounted to approximately $355,000 (1964 dollars) in Polk County.[7]

January 1974

Heavy snow and freezing rain, and a series of mild storms caused snowmelt and rapid runoff in mid-January 1974. Nine counties in Oregon were declared disaster areas, including Polk County. Several roads were closed due to high water and damage to bridges and stream banks from the storms and flooding cost and estimated $575,000. This figure did not include damage to homes, pastures, livestock or crops.[8]

January 1987

In a 24-hour period between January 31 and February 1, 1987 three and a half inches of rain fell on the Dallas area. The heavy rains caused the Willamette and Luckiamute Rivers and Rickreall Creek to swell their banks causing mudslides and damaging homes and highways. Two hundred and sixty five residents of Rickreall lost power and 20 experienced water outages. The erosion of a stream bank that caused a tree to fall and break a water main caused the disruption in water supply.[9]

February 1996

Residents of Polk County experienced more than one flood during 1996. In February 1996, a combination of snow-pack, warm temperatures, and record-breaking rains caused streams to rise to all-time flood record levels.[10] Much of the reason for the record flood levels was that in 1996, Mt. Laurel, fifteen miles northwest of Falls City received a record breaking 17 feet of rain, more than any other location in Oregon's recorded history. Much of this rainfall flowed into the Luckiamute River and eventually Rickreall Creek where flooding occurred.[11]

This event caused nearly $3 million in damages within Polk County and resulted in one flood related death. The Willamette River rose from 14 to 34 feet in Independence forcing dozens of residents to evacuate their homes. Edgewater Street in Salem was flooded and a highway to the coast was closed because of rockslides.[12]

November 1996

The Willamette Valley region was hard hit again by rains and flooding in November of 1996. Once again, Polk County escaped the storms relatively unscathed, with the exception of a 70-foot section of Parker road near Independence that was wiped out by a torrent of floodwaters, which left a 15-foot deep hole. Four motorists drove vehicles, including a semi-truck, into the hole. There were no deaths, but one motorist was severely injured.[13]

January 1997

The flood event that began in December 1996 and continued to January 5, 1997, prompted County Commissioners to declare a state of emergency and caused approximately $250,000 of damage to the county. The Willamette River rose to 28.8 feet and the Luckiamute River rose to 27.8 feet, both nearly one foot above flood stage.[14] Two hundred and fifty Dallas residents lost power. Flooding and high water closed many county roads, especially in the Monmouth/Independence area. In Independence, the bandstand in Riverview Park was submerged.[15]

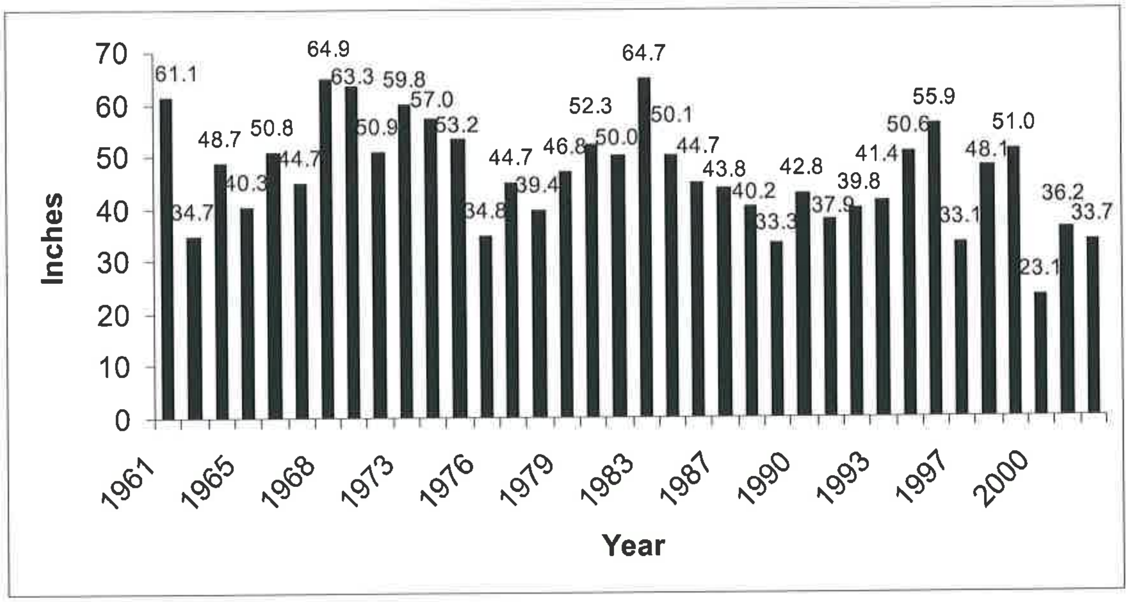
Polk County Flood: Wallace Bridge of the Yamhill River, 1964 (Polk County)

Repetitive Flood Losses in Polk County

The properties in and near the floodplains of Polk County are subject to flooding events almost annually. Since flooding is such a pervasive problem throughout the county, many residents have purchased flood insurance to help recover from losses incurred from flooding events. Flood insurance covers only the improved land, or the actual building structure. Although flood insurance assists in recovery, it can provide an inappropriate sense of protection from flooding. Many residents who

Flooding is most common from October through April, when storms from the Pacific Ocean, 60 miles away, bring intense rainfall to the area.[21] Polk County receives approximately 51 inches of rain on average each year (see Figure 6.1 & 6.2). During the rainy season, monthly rainfall totals average far higher than other months of the year. This results in high water, particularly in December and January. The larger floods are the result of heavy rains of two-day to five-day durations augmented by snowmelt at a time when the soil is near saturation from previous rains. Frozen topsoil also contributes to the frequency of floods.[22]

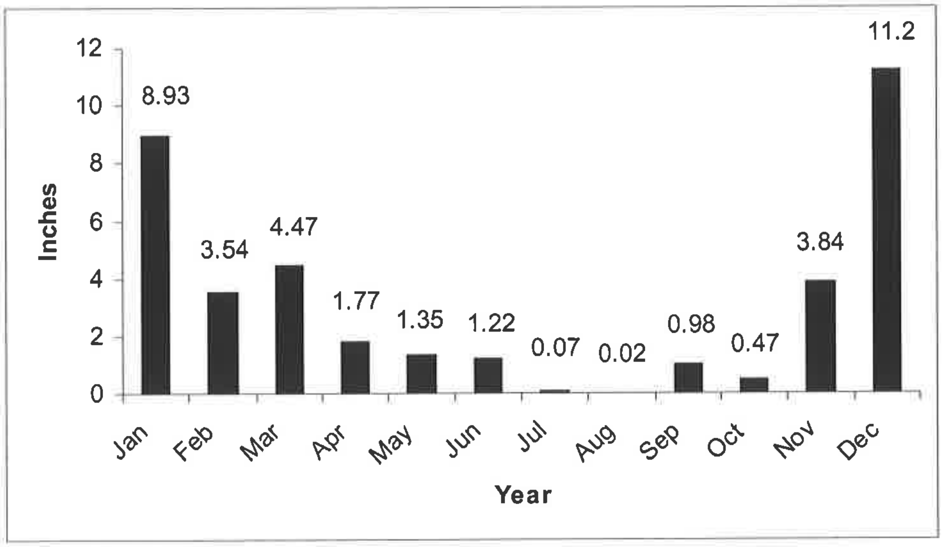
Figure 6.1 Annual Precipitation in Polk County, Oregon, 1961-2002



Source: Oregon Climate Service
*Data missing for the following incomplete years: 1969-1970, 1981,1985,1994

28

Figure 6.2 Average Monthly Precipitation Salem, OR 2002



Oregon Climate Service, Zone 2 Climate Data Archives. Webpage: http://www.ocs.orst.edu/

Geography

Polk County is located in the Mid-Willamette Valley in northwest Oregon. It is comprised of 735 square miles and extends west from the Willamette River, to the crest of the Coast Range. The eastern part of the county sits on the main valley floor and on an alluvial floodplain. Polk County has a modified marine climate that varies widely from east to west.

Floodplain Terminology

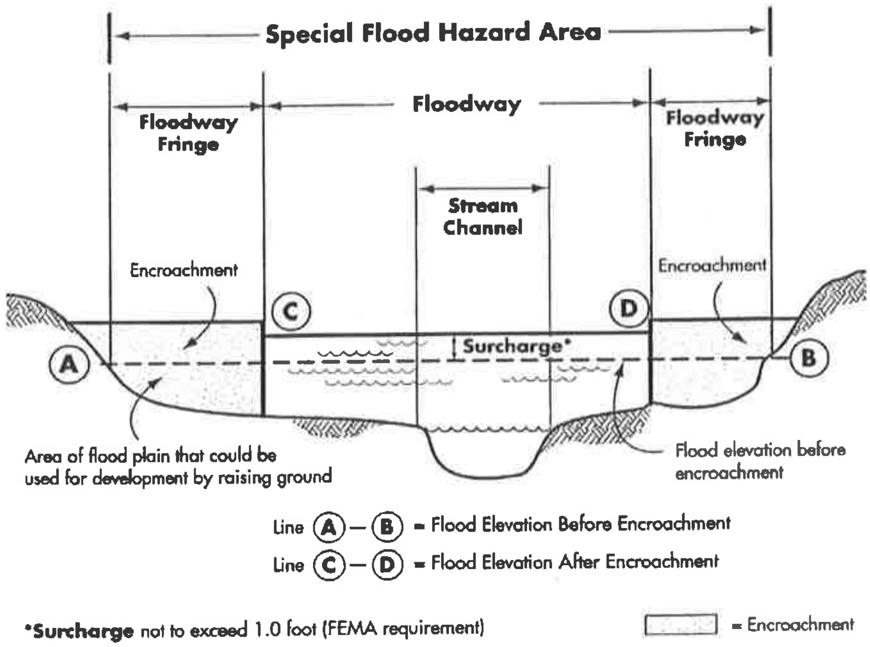
Floodplain

A floodplain is a land area adjacent to a river, stream, lake, estuary, or other water body that is subject to flooding (see Figure 6.3). This area, if left undisturbed, acts to store excess floodwater. The floodplain is made up of two sections: the floodway and the flood fringe.

Floodway

The floodway is one of two main sections that make up the floodplain. Unlike floodplains, floodways do not reflect a recognizable geologic feature and are defined for regulatory purposes by the National Flood Insurance Program (NFIP) as "the channel of a river or other watercourse and adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than one foot." The floodway carries the bulk of the floodwater downstream and is usually the area where water velocities and forces are the greatest. NFIP regulations require that the floodway be kept open and free from development or other structures that would obstruct or divert flood flows onto other properties. Floodways are not mapped for all rivers and streams but are generally mapped in developed areas.

Figure 6.3 Floodplain Schematic



Source: Missouri Emergency Management Agency. March 1999. *Floodplain Management in Missouri.*

Flood Fringe

The flood fringe refers to the outer portions of the floodplain, beginning at the edge of the floodway and continuing outward. This is the area where development is most likely to occur, and where precautions to protect life and property need to be taken. While the Polk County Zoning Ordinance does not define the flood fringe, it does set forth a flood overlay zone that, with some exceptions, prohibits subdivisions, storage of materials and equipment and residential and non-residential development.[23]

Base Flood Elevation (BFE)

The term "Base Flood Elevation" refers to the height of the base flood, usually in feet, in relation to the National Geodetic Vertical Datum of 1929, the North American Vertical Datum of 1988, or other datum referenced in the Flood Insurance Study report, or average depth of the base flood, usually in feet, above the ground surface.[24] FEMA completed a vertical datum conversion from the National Geodetic Vertical Datum of 1929 to the North American Vertical Datum of 1988, by adding 3.4 feet to all flooding sources in Polk County.[25] This revision includes floodplain maps showing areas that would be inundated by the base (100-year) flood.

Base flood elevations can be set at levels other than the 100-year flood. Some communities choose to use higher frequency flood events as their base flood elevation for certain activities, while using lower frequency events for others. For example, for the purpose of stormwater

Flood Insurance Studies and FIRMs produced for the National Flood Insurance Program (NFIP) provide assessments of the probability of flooding at a given location. FEMA conducted many Flood Insurance Studies in the late 1970s and early 1980s. These studies and maps represent flood risk at the point in time when FEMA completed the studies. FEMA flood maps are not entirely accurate. These studies and maps represent flood risk at the point in time when FEMA completed the studies, and do not incorporate planning for floodplain changes in the future due to new development. Although FEMA is considering changing that policy, it is optional for local communities. Artificial and natural changes to the environment have changed the course of many of the rivers in the county, as well as their associated floodplain boundaries.[31]

FEMA provided Polk County with a preliminary Flood Insurance Study (FIS) and preliminary Flood Insurance Rate Maps (FIRMs) dated February 17, 2005 for Ash Creek and the North Fork Ash Creek, and an overflow channel of Ash Creek. The county is reviewing the report and maps, and will be meeting with FEMA in April 2005.

Revised Flood Insurance Rate Maps (FIRM) will be used by lending institutions and insurance agents in determining who must purchase flood insurance and in determining the cost of the insurance. Polk County and the cities of Dallas, Falls City, Independence and Monmouth will use the maps for floodplain management and permitting purposes.

Flood Mapping Methods and Techniques

Although many communities rely exclusively on FIRM's to characterize the risk of flooding in their area, there are some flood-prone areas that are not mapped but remain susceptible to flooding. These areas include locations next to small creeks, local drainage areas, and areas susceptible to artificially caused flooding.

In order to address this lack of data, many jurisdictions have taken efforts to develop more localized flood hazard maps. One method that has been employed by some jurisdictions includes using high-water marks from flood events or aerial photos, in conjunction with the FEMA maps, to better reflect the true flood risk.

The use of GIS (Geographic Information System) is becoming an important tool for flood hazard mapping. FIRM maps can be imported directly into GIS, which allows for GIS analysis of flood hazard areas. Communities find it particularly useful to overlay flood hazard areas on tax assessment parcel maps. This allows a community to evaluate the flood hazard risk for a specific parcel during review of a development request. Coordination between FEMA and local planning jurisdictions is the key to making a strong connection with GIS technology for the purpose of flood hazard mapping.

FEMA and the Environmental Systems Research Institute (ESRI), a private company, have formed a partnership to provide multi-hazard maps and information to the public via the Internet. ESRI produces

GIS software, including ArcView© and ArcInfo©. The ESRI Web site has information on GIS technology and downloadable maps. The hazards maps provided on the ESRI site are intended to assist communities in evaluating geographic information about natural hazards. Flood information for most Oregon communities is available on the ESRI Web site. Visit http://www.esri.com for more information.

Flood Hazard Assessment

Hazard Identification

Hazard identification is the first phase of flood-hazard assessment. Identification is the process of estimating: (1) the geographic extent of the floodplain (i.e., the area at risk from flooding); (2) the intensity of the flooding that can be expected in specific areas of the floodplain; and (3) the probability of occurrence of flood events. This process usually results in the creation of a floodplain map. Floodplain maps provide detailed information that can assist jurisdictions in making policies and land-use decisions. Map 5 shows 100-year floodplains within Polk County.

Vulnerability Assessment

Vulnerability assessment is the second phase of flood hazard assessment. It combines the floodplain boundary, generated through hazard identification, with an inventory of the property within the floodplain. It identifies the number of properties at risk from flooding, and the dollar value of the property at risk. Floodplain data for Polk County can be used to conduct a preliminary vulnerability assessment for flood and drainage hazard areas.

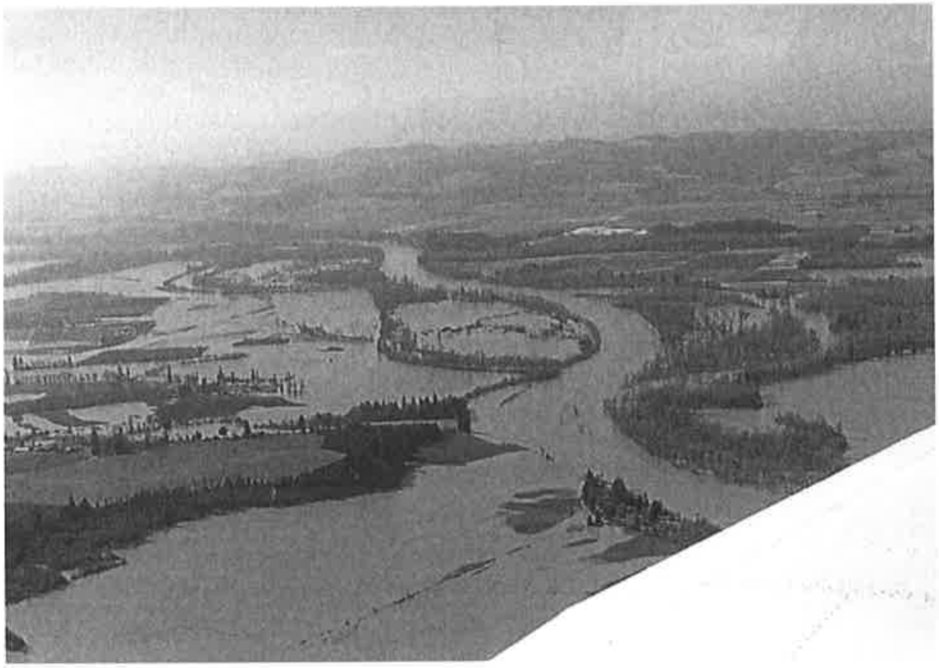
Risk Analysis

Risk analysis is the third and most advanced phase of a hazard assessment. As such, it builds upon the hazard identification and vulnerability assessment.

A flood risk analysis for Polk County should include two components:

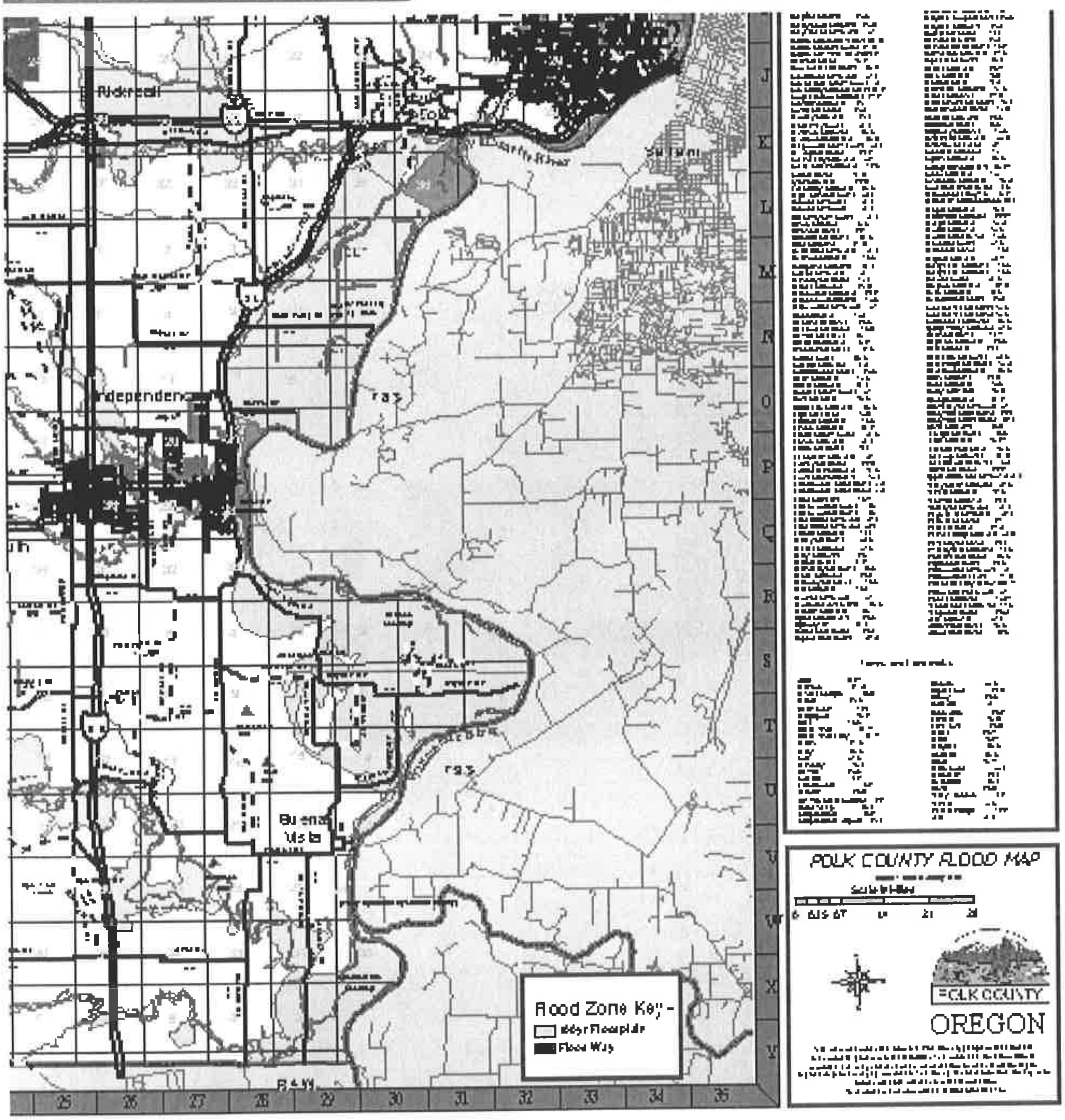
(1) The amount of loss to both property and life that may result from a flood event (defined through the vulnerability assessment); and,

(2) The number of flood events expected to occur over time. Within the broad components of a risk analysis, it is possible to predict the severity of damage from a range of events. For example, a risk analysis can be conducted for both 25-year (smaller storm) floodplains (Drainage Hazard Areas), and 100-year (larger storm) floodplains. Over time, the Drainage Hazard Areas will flood more often than areas within a 100-year floodplain, exposing properties in Drainage Hazard Areas to a greater risk of flood damage. Depending on the impacts resulting from a 25-year flood event versus a 100-year flood event, however, and the amount of life and property exposed to the different hazard events, the level of risk may vary.



Our Floodplain Program

Along with the Willamette River, Marion County has many streams and rivers that are subject to flooding. Under certain conditions, such as the storm events that occurred from Dec. 1996 through Feb. 1997, rain and melting snow cause these streams and rivers to overflow their banks. As you can see from these pictures, homes and property suffered significant damage:



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April 27, 2015

5079-B 2015 EVALUATION LTR

City of Salem
Public Works Department
471 High Street SE
Salem, Oregon 97301

Attention: Ken Roley, PE

SUBJECT: Geotechnical Consultation
2015 Slope Maintenance Planning
South River Road Rock Slopes
Salem, Oregon

This letter provides our recommendations associated with planning the 2015 maintenance of the rock cut slopes along the east side of South River Road in Salem, Oregon, at the location shown on the Vicinity Map, Figure 1. Our work included a geologic reconnaissance of the site and engineering analyses. This letter summarizes the work completed, provides our recommendations for prioritizing repair and maintenance of the rock cut and draped mesh rockfall protection system, and provides preliminary cost estimates for the recommended maintenance and repairs. Recommendations for the repair include design of new anchors to secure the draped mesh system and methods for reducing damage to existing anchors.

BACKGROUND

The intent of the draped mesh system on this rock cut is to direct rockfall debris into the catchment area and reduce the risk of rocks bouncing away from the slope and onto the roadway. The catchment area between the cut slope and concrete barriers at the edge of the sidewalk is relatively narrow, typically 5 to 6 ft wide. A chain link fence is located on top of the concrete barriers. From our correspondence with you, we understand localized rockfall generating less than about 50 cu yd of debris is usually contained within the catchment area. Rockfall generating more than 50 cu yd of debris typically exceeds the capacity of the catchment area and spills onto the sidewalk and roadway. A January 7, 2015, memorandum prepared by City of Salem Public Works Department that summarizes the history of the South River Road rockslide area is provided in Appendix A. As described in the historical narrative, accumulated debris has been removed from the rockfall catchment area 20 times during the past 11 years as part of maintenance.

Draped mesh systems are generally suitable to contain occasional rockfall debris up to about 2 ft in diameter. Since the draped mesh system was installed on this rock cut in the 1990s, several large-diameter rockfall and large rockslides have damaged the draped mesh system and concrete barrier. The most recent event occurred on December 16, 2014, when a rockslide about 30 to 50 ft wide generated an estimated 400 cu yd of debris and temporarily closed the roadway (2014 rockslide). Several panels of the draped mesh and at least six of the anchors that secure the draped mesh system to the face of the slope were damaged by the rockslide. The location of the 2014 rockslide is shown on Figure 2.

Prior to our reconnaissance for this project, City personnel completed a land survey to locate the property lines in the area uphill of the rock cut. Based on this survey, most of the recent rockslide area is located on private property. The City has a 10-ft-wide sewer easement directly uphill of the rock cut. At the closest point, the sewer line is estimated to be about 25 ft from the crest of the rock cut.

In this letter, the ends of rock cut are referred to as north and south. When viewing the cut from the roadway, the north end of the rock cut is to the left and the south end is to the right. Rock fractures discussed in this letter can include joints, bedding planes, and any other breaks or discontinuities in the rock. The terms used to describe the rock are defined in Table 1.

PREVIOUS WORK

GRI has provided consultation to the City of Salem (City) associated with rock cuts along South River Road since 1990. Our work has been summarized in several reports and memoranda. In 1990, GRI completed a geotechnical investigation and prepared construction specifications for remedial measures consisting primarily of scaling the rock slopes to remove loose materials and installing a draped mesh system intended to direct rockfall debris into a narrow catchment area between the rock cut and the sidewalk.

Remedial measures completed in 1990 included heavy scaling of the rock cut slope using a wrecking ball for the upper portion of the cut slope and a trackhoe excavator on the lower portion of the slope. Trees growing on the face of the rock cut slopes were removed. The base of the rock cut was steepened by excavating to widen the catchment area. Chain link mesh was draped over most of the rock cut after scaling and tree removal. The intent of the draped mesh system is to direct rockfall debris into the catchment area to reduce the risk of rocks bouncing away from the slope and onto the roadway.

In 2011, GRI evaluated the condition of the rock cuts and provided recommendations for long-term rockfall mitigation alternatives, as well as interim remedial measures that could be implemented with less expense and maintenance items that should be performed until long-term mitigation measures are constructed. These recommendations were summarized in our June 30, 2011, letter to the City entitled, "Long-Term Mitigation Alternatives, South River Road Rock Cut Slopes, Salem, Oregon."

PROJECT DESCRIPTION

We understand the City plans to perform maintenance on the rock cut slopes and draped mesh rockfall protection system in 2015. The maintenance may involve replacing anchors that were damaged by the December 16, 2014, rockslide (2014 rockslide) and scaling in selected areas to remove debris, vegetation, overhanging rock and loose rock from the face of the cut. The existing draped mesh will be removed from areas to be scaled and replaced with new wire mesh. We will evaluate possible methods to reduce the risk of anchor damage when the draped mesh is damaged by rockslides or large rockfalls.

The intent of our work for this project is to identify a scope of maintenance and repairs that can be accomplished this year to reduce the risk of large-volume rock slides that exceed the capacity of the rockfall catchment area and spill into the road. The maintenance and repairs will be interim measure while the City develops and funds long-term rockfall and rockslide mitigation measures.

SITE RECONNAISSANCE

An engineering geologist and geotechnical engineer from GRI visited the site on March 4 and March 18, 2015. The reconnaissance focused on the rock cut slope in the area of the 2014 rockslide, the area directly south, and the hillside above the rock cut, where replacement anchors for the draped mesh rockfall protection system will be installed. The purpose of the reconnaissance was to observe and evaluate conditions that could affect design and construction of the repairs, such as the condition of the rock, springs and seeps, depth of the soil uphill of the rock cut, and indications of slope instability. The reconnaissance also focused on prioritizing other maintenance items needed for the rock cut slope and draped mesh system. Photographs taken during the reconnaissance are provided in Appendix B.

GRI completed a reconnaissance-level survey using a clinometer and tape measure to develop a cross section of the area directly uphill of the 2014 rockslide. From the top of the rock cut, the ground surface slopes upward to the east at about 32° and gains about 15 ft in elevation before reaching the approximately 7-ft-wide access path on the sanitary sewer alignment that parallels the top of the rock cut. Based on the stakes placed by the City survey, the east (uphill) edge of the sewer easement is located near the middle of the access path at this location. Uphill of the access path, the ground surface slopes up to the east at about 20° to 25°.

GRI completed a series of drive probe explorations along the cross section described above to evaluate the soil thickness. The probe consists of 1/2-in.-diameter steel pipe fitted with an oversized pipe cap and was driven into the ground using a fencepost driver. The probe was driven into the ground until practical refusal became apparent. The expendable pipe cap is left in the ground when the pipe was removed. The drive probes reached refusal at a depth of about 4 ft near the top of the rock cut, 6 ft at the uphill side of the sewer alignment, and about 3 ft at two locations 15 ft east (uphill) of the sewer alignment. A drive probe at the west (downhill) edge of the sewer alignment disclosed about 4 ft of relatively loose material with gravel and cobbles, which is presumably fill placed to create the 8-ft-wide path along the sewer alignment. Below the fill, the drive probe disclosed 4 ft of relatively soft soil before encountering refusal at a depth of 8 ft.

GRI accessed the steep hillside to the south of the 2014 rockslide using roped safety techniques. The ground surface in this area slopes down to the top of the rock cut at about 32° (1 1/2H:1V). Chain-link mesh covers the slope and extends about 30 to 35 ft uphill of the rock cut. Several large tree clumps and trees up to about 8 in. in diameter are growing through the mesh. Anchors visible at the top edge of the mesh consist of 3/4-in.-diameter threaded bar drilled vertically into the ground. The anchors penetrate the mesh. The mesh and a wire rope that parallels the top edge of the mesh (top rope) are attached to the anchors by steel plates retained with threaded nuts. The anchors are spaced about 8 ft apart along the top rope. This spacing is approximately the width of the wire mesh panels. Ground cracks up to 2 ft deep are located on the uphill side of the two anchors located closest to the 2014 rockslide and appear to have been formed when the top rope was pulled in the downhill direction by the mesh that was entangled in the 2014 rockslide.

GRI also evaluated the conditions visible on the rock cut from the sidewalk adjacent the base of the cut along South River Road. Particular attention was directed to the area of the 2014 rockslide and the area directly to the south (to the right when viewed from the roadway). A weathered basalt flow is exposed in the area of the 2014 rockslide. The bottom of the weathered zone is near mid-height on the cut slope, and the top is about 10 to 15 ft below the crest of the cut slope. The weathered zone has somewhat spheroidal weathering, which is visible as rounded surfaces about 6 to 12 in. in diameter, rather than angular fracture surfaces that occur in less-weathered rock. The rock layers exposed on the site dip gradually down to the north, making the spheroidal weathering surfaces in the weathered basalt flow visible near eye level at the north end of the rock cut.

A younger, less-weathered basalt flow is located on top of the weathered basalt layer. The younger basalt layer forms the near-vertical scarp at the top of the 2014 rockslide area and the top of the rock cut slope directly to the north. Relatively flat fracture surfaces are visible in the scarp, indicating the rock exposed in the scarp is less weathered than the underlying layer of rock. The scarp height varies and is estimated to range from about 5 to 10 ft.

The side scarp at the right (south) edge of the 2014 rockslide area has an estimated height of about 4 to 8 ft and ranges from nearly vertical to overhanging. A large clump of trees is growing through the mesh at the top of the rock cut about 6 ft left (south) of the side scarp. Roots of these trees are overhanging the cut slope.

Areas with overhanging slopes and tree clumps growing through the wire mesh are visible north of the 2014 rockslide area. The top of the draped mesh is below the crest of the rock cut slope in an area starting about 280 ft from the north end of the rock cut. South of the 2014 rockslide, there are several areas where woody brush and small trees are growing through the wire mesh on the cut slope.

CONCLUSIONS AND RECOMMENDATIONS

General

The rockslide that occurred in December 2014 may have been related to a weathered layer or zone of basalt rock located midslope in the cut. The weathered basalt is overlain by a layer of less-weathered basalt that is visible in the near-vertical scarp formed by the rockslide. In general, the strength of the rock decreases as it weathers. The overall strength of a rock mass is controlled by the fractures in the rock. The shear strength across fractures is lower for fractures with openings (apertures) between the two sides and for fractures in soft or weathered rock. In rock cuts, fractures can widen over time due to gravitational loading. The rate of widening is accelerated by processes such as freeze-thaw and root wedging.

We anticipate damage to anchors that support the draped mesh system can be reduced by installing wire rope anchors with significantly greater capacity than the anchors damaged by the 2014 rockslide. In addition, wire rope anchors are flexible and, therefore, more resistant to lateral loading than steel bar anchors.

Our work has identified several repairs and maintenance needed for the rock cut and draped mesh rockfall protection system. A discussion of prioritization and recommendations for repair and maintenance are provided below.

Work Prioritization

Repair and maintenance of the rock slope and draped mesh rockfall protection system can be prioritized by evaluating the reduction in potential risk associated with each task. For the purpose of discussion, risk is related to the potential for rockfall or rockslides that could cause road closures or damage to the draped mesh system. Risk is considered to increase as the size of the hazard area increases. Hazards that could occur relatively soon are also considered to have a greater risk. Repairing damaged portions of the draped mesh system, including the anchors, is also considered a priority. We have prioritized the recommended work into three categories: 1) High Priority items than should be addressed as part of 2015 repairs and maintenance, 2) Moderate Priority items that should be addressed soon (within the next 1 to 2 years), 3) and Routine Maintenance items that should be addressed on an annual or biennial basis.

High Priority: 2015 repairs and maintenance

- Excavation to trim the side scarp formed by the 2014 rockslide
- New anchors to replace anchors damaged by the 2014 rockslide
- Scaling the scarp formed by the 2014 rockslide
- Scaling to trim back the oversteepened and overhanging top of the rock cut for the area north of the 2014 rockslide
- Remove trees with roots that overhang the top of the cut slope
- Install new mesh to replace mesh damaged by the 2014 rockslide and mesh removed for scaling and rock excavation

Moderate Priority: Should be addressed within the next 1 to 2 years

- Remove trees growing between the rock cut and sewer alignment
- Remove trees that are growing though the mesh
- Remove all woody vegetation within the same limits as tree removal
- Remove overhanging portions at top of rock cut to the north of the 2015 repairs
- Lift existing mesh above the top of the cut slope

Routine Maintenance: Annual or biennial basis

- Remove all trees and woody vegetation that grows though the mesh
- Remove any trees or woody vegetation that establish between the rock cut and sewer alignment
- Continue to remove rockfall debris from the catchment area

The repair and maintenance items prioritized above are described in the following sections.

Excavation

The side scarp at the south edge of the 2014 rockslide and area directly to the south appear to have a high risk for additional rockslide or large-volume rockfall. We recommend excavation to significantly trim back the side scarp and overhanging slope caused by raveling of the cut slope. As viewed from the roadway, the side scarp should be trimmed by removing a wedge of rock starting at the base of the side scarp, about 10 to 12 ft below the crest of the cut slope that remained in place to the right of the side scarp, and extending upward to the right about ½H:1V. The height of the side scarp decreases farther up the slope and is estimated to be about 5 ft tall where it transitions into the headscarp at the top of the 2014 rockslide. We anticipate the excavation can be completed using a trackhoe excavator equipped with an extended-reach arm. The area of excavation should be scaled using hand tools before new mesh is placed. We estimate about 60 cu yds of rock will be removed by this excavation, and replacement of the draped mesh system in this area will require 1,800 sq ft of mesh and three new anchors.

Tree Hazards

Root growth tends to increase the rate of large rockfall from cut slopes in highly fractured rock, such as this site. Large trees, especially deciduous trees, can have extensive and deep root networks, as evident by root mats visible on the fracture faces exposed by recent rockfall. We recommend removing any trees and brush growing on the cut slopes and on the hillside between the top of the cut slope and the sewer alignment located uphill of the rock cut.

Several large trees are located on the upper portion of the slope near the edge of the rock cut. There is a risk that raveling of the rock slope or shallow slope instability in the soil overlying the rock cut will eventually remove support of these trees. Toppling of large trees near the edge of the slope above the rock cut could damage the draped mesh system.

In our opinion, the area uphill of the 2014 rockslide and the area where excavation is recommended south of the 2014 rockslide are the highest priority for tree removal and will need to be done to complete other high-priority items. Removal of trees with roots that overhang the cut slope should also be considered a high priority. Removal of trees from the remaining areas between the top of the rock cut and sewer alignment uphill of the cut should be completed soon and can be scheduled as part of the programmatic maintenance over the next few years if not completed as part of 2015 maintenance.

Scaling

Near-vertical or overhanging slopes have formed in several areas at the top of the cuts as the result of rockslides and also from gradual raveling of rock from the cut slopes. Trees and woody brush frequently overhang these areas. After the overhanging vegetation is removed, scaling of the rock cut should be performed to decrease the risk of large-volume rockfall that could damage the draped mesh system. We recommend scaling these areas to allow removal of the overhang in a controlled manner. The slope in these areas should be ½H:1V or flatter after scaling, as shown on Figure 3. Based on our observation on the site, the highest priority areas for scaling vertical and overhanging slopes are the crest of the scarp from the 2014 rockslide and adjacent area extending about 50 ft to the north.

Scaling should be completed prior to installing any new wire mesh. Scaling efforts in areas of new mesh should be concentrated on trimming back overhanging portions of the cut slope, smoothing protrusions that may trap debris against the mesh, and removing loose oversized blocks with maximum dimension larger than 3 ft, which could damage the mesh.

It should be recognized that the reduced risk of rockfall following scaling of the rock face will be temporary. In our opinion, there would be no significant long-term decrease in the rate of rockfall caused by gradual raveling of the rock cut within a few years after scaling. Therefore, scaling the entire rock cut is not a substitution for a rockfall protection system as a long-term measure.

Anchor Design

We anticipate damage to anchors that support the draped mesh system can be reduced by installing wire rope anchors with significantly greater capacity than the anchors damaged by the 2014 rockslide. Wire rope anchors are flexible and, therefore, more resistant to lateral loading than steel bar anchors.

The anchors should be regularly spaced on about 25-ft centers and connected to the horizontal wire rope at the top of the wire mesh using wire rope extensions. Additional anchors should be installed in locations with significant changes in topography along the top of the rock cut, such as the side scarp at the south edge of the 2014 rockslide. We anticipate three new anchors will be needed to replace anchors damaged by the 2014 rockslide, and two additional anchors will be needed to allow scaling and trimming of the top of the cut slope for the 50-ft-wide section adjacent to the north edge of the 2014 rockslide.

The new anchors should be located at least 20 ft above the crest of the rock cut to reduce the risk that anchors could be damaged by slope instability and localized "pop outs" that may occur in the soil above the rock cut. Replacement anchors on the downhill side of the sewer alignment would extend beneath the sewer, and there would be a significant risk of damaging the sewer during anchor installation. Therefore, we recommend installing the new anchors uphill of the sewer. The connections between the anchors and wire mesh will be fastened with cable clips and could be disassembled if needed for sewer maintenance.

We recommend installing wire rope-type tendon anchors in drilled boreholes, as shown on the attached Oregon Department of Transportation (ODOT) standard detail for wire mesh/cable net anchors, see Appendix C. Due to the relatively shallow depth to rock, we anticipate most anchors can likely be completed following the wire rope-type rock anchorage detail shown on attached ODOT standard details sheets 2201 and 2203. We anticipate wire-rope tendon anchors installed 10 ft deep perpendicular to the slope and penetrating at least 5 ft into the underlying basalt will be suitable to provide an ultimate capacity of 20 kips applied parallel to the slope. The ultimate anchor capacity includes a factor of safety to account for shock loads from falling debris and rockslides. In the event an anchor is damaged, the anchors and horizontal wire rope at the top of the draped mesh include factors of safety that should allow forces to be transferred to adjacent anchors until repairs are made.

The risk of anchor damage caused by shock loading can be reduced by installing braking elements on the lead ropes that attach each anchor to the draped wire mesh. The braking elements would reduce the peak force applied to the anchors if the mesh is damaged by a rockfall or rockslide. Braking elements are typically used to dissipate impact loads on rockfall catchment fence systems. The braking elements deform when heavily loaded and require replacement afterwards.

We recommend testing at least 25% of the anchors to the ultimate capacity. The ODOT standard specifications can be used as a guideline for testing procedures. Ideally, the test loading should be applied in the direction the anchors will be loaded by the draped mesh. This loading can be accomplished for most anchor locations on the site using a large tow truck, such as those used to recover semi-trucks. A cable extending from the anchor to the recovery truck located near the base of the rock cut will allow the direction of pull to approximate the direction the mesh will apply load to the anchor. This test setup will require a tensionometer to measure the load at the head of the anchor. Anchor deflection will also be measured. Alternatively, the anchors can be tested in tension at the anchor location using a portable hydraulic ram equipped with a calibrated pressure gauge. If anchor testing will not be completed, we recommend increasing the embedment length of the anchors to compensate for the uncertainty resulting from not having load tests to confirm the design assumptions. For preliminary purposes, we recommend adding 2 ft of embedment into the rock if anchor testing is omitted. GRI can provide final anchor design recommendations as plans and specifications are prepared.

Draped Mesh

We anticipate the wire mesh will need to be replaced in areas that are scaled and where trees growing through the mesh are removed from the rock cut. Mesh panels should be continuous top to bottom, i.e., no horizontal seams. We recommend using a horizontal wire rope at the top of the mesh system to distribute stresses in the mesh. Vertical and intermediate support cables should not be used. The bottom of the mesh should extend to within 3 to 5 ft of the bottom of the rock slope and a horizontal cable should not be used at the bottom of the mesh. The steel wire mesh should have factory-applied corrosion protection. The use of chain-link fence material should be avoided.