Technical Report on Ground Water Storage Alternatives for the Yakima River Basin the Integrated Water Resource Management Alternative

In support of the Yakima River Basin Water Storage Feasibility Study
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EXECUTIVE SUMMARY

The Washington State Department of Ecology (Ecology) is preparing a Final Environmental Impact Statement (Final EIS) to evaluate an Integrated Water Resource Management Alternative. The current water supply and storage capacity within the Yakima River Basin does not meet the water supply demands in all years and affects the Yakima River Basin's economy, which is agriculture-based. Water resources are also vital to the basin's aquatic resources—specifically those resources supporting anadromous fish. Ecology seeks to identify a means of increasing water supplies available for purposes of improving anadromous fish habitat and meeting irrigation and municipal needs. This report supports this effort and evaluates the feasibility of ground water storage alternatives as part of the state's alternatives analysis.

The ground water storage alternatives include surface recharge with passive recovery, and direct injection with active and passive recovery. These alternatives include placing water in the aquifer system and storing it to realize benefits in the form of increased streamflow from increased ground water discharge, recovery of the stored water for out-of-stream uses, and/or replenishing depleted ground water storage. The ground water storage alternatives are conjunctive use tools in which the use of surface water and ground water can be coordinated to minimize impacts to the hydrologic system and provide environmental benefits. Use of ground water storage, whether as a direct supply or as an indirect means to increase stream flows, can increase the water supply in the Yakima River basin and conserve reservoir storage.

Surface Recharge

Surface recharge with passive recovery involves diverting and infiltrating surface water into a recharge basin during periods of high stream flow and allowing it to naturally discharge back to a stream. The objectives for applying the surface recharge (passive recovery) method to locations in the Yakima River Basin include:

1. Offset impacts of current irrigation surface water withdrawals on stream flows
2. Improve reliability for certain agricultural water demands during water short years by increasing Total Water Supply Available (TWSA)
3. Provide capability for surface application and storage of reclaimed water

The volume and timing of water diverted to an infiltration pond and the subsequent timing and volume of return flow to the stream were evaluated using two approaches: 1) target return flow profile; and 2) excess surface storage. The target return flow profile approach identified a desired condition for ground water return flows, and examined the amount of infiltration and total area of infiltration ponds required to achieve the target infiltration profile. The excess surface storage approach evaluated the amount of infiltration and total area required when the availability of water for infiltration is constrained by the historical storage volumes in reservoirs in excess of entitlements and flow requirements.

The results of the first approach, the target return flow approach, indicate that to “normalize” ground water return flows to a level that would be consistent from year-to-year requires delivery of significant amounts of water during July and August. While there will be some flexibility in optimizing the system by choosing areas with differing stream depletion factors (SDF) values, it is not likely that surface recharge alone will offset the effects of drought conditions on stream flows or TWSA for downstream water right holders.

The excess surface storage approach used the historical monthly availability of reservoir storage for the period from 1978 to 2000 to determine which months there was “excess” reservoir storage that could be diverted into infiltration ponds. It was assumed that between 10,000 and 20,000 acre-feet (AF) of water could be released when excess storage exceeded 25,000 AF. In many months, there is no excess storage, and no infiltration is assumed during that month. The annual delivery volume, on average, is expected to be 33,000 AF. The expected delivery volume in drought years is expected to range from 10,000 to 20,000 AF for the year. This approach does not account for all operational flows, but is adequate for this preliminary analysis.

The surface recharge analysis used the SDF view program, version 2.0.11, to estimate the monthly return flow (or accretion) to the river based on monthly infiltration volumes and a range of stream depletion factors (SDF). The stream depletion factor is a function of the distance between the site and a stream, the transmissivity of the aquifer, and the specific yield of the aquifer. The SDF view program generates a stream depletion function that shows how the return flow peaks and decays over time. Smaller SDF values result in a more rapid peak and decay in return flow which means that more of the infiltrated volume of water reaches the stream within a few months of the infiltration event. SDF values of 30, 40, 50, and 60 days were used in the analysis because they would result in larger volumes of same-season return flow.

The streamflow improvements from surface recharge were estimated as a percent of the historical monthly flows at Umtanum gauge. In terms of streamflow improvements, the return flow estimates suggest that infiltration of 10,000 AF/month during months when there is excess TWSA will result in average and maximum August stream flow improvements of 2.3 to 5.2 percent at Umtanum gauge. The average stream flow improvement in August is expected to range from 4,903 to 5,244 AF (80 to 85 cubic feet per second (cfs)), depending on the SDF value at the site. Stream flow improvements of up to 12 to 15 percent are predicted for drought years (1993) in October. This represents approximately 4,900 to 6,200 AF (80 to 100 cfs) of return flow from surface recharge. If 20,000 AF/month were infiltrated during months when there is excess TWSA, August stream flow improvements of 4.7 to 9.6 percent are predicted. This represents approximately 10,100 to 14,400 AF (170 to 240 cfs) of return flow from surface recharge. Under a 20,000 AF scenario, stream flow improvements of 6 to 28 percent are predicted for drought years (1993) in September and October, depending on the relative proportion of areas with a SDF value of 30 or 60. This represents approximately 5,700 to 11,000 AF (95 to 185 cfs) of return flow from surface recharge.

There were not enough data available to identify specific sites and SDF properties for surface recharge. However, a screening of potential areas was conducted based on surficial geology, land cover, estimated aquifer properties, and distance buffers around the Yakima River and main tributaries. The distance buffers are based on conditions within each basin that would result in a SDF of 30, 40, 50, or 60. Site identification will require a site investigation, including drilling and aquifer testing to obtain estimates of hydrogeologic properties.

For the Yakima River Basin, total land area needed for surface recharge sites could range between 166 and 500 acres for similar infiltration capacities, with an expected area of about 300 acres. Total construction costs could range from $54 million to $164 million, with an expected cost of $98 million. Assuming that surface recharge would return an average of about 33,000 AF annually from ground water storage, the annual cost per AF for ground water storage is estimated to be in the range of $1,646 to $4,958 per AF, with an expected value of $2,975 per AF. Annual operation and maintenance (O&M) costs are estimated to be about $2.1 million per year.

Injection Recharge

Injection recharge is a method that injects water via wells into a deep subsurface geologic formation. The injected water may or may not be recovered depending on the objective of the recharge. Aquifer storage and recovery (ASR) is the term used when the stored ground water is actively recovered for potable (municipal) and nonpotable uses. When the storage is allowed to discharge naturally, it is called injection with passive recovery.

The objectives of direct injection within the Yakima Basin are to:

- Replace direct surface water diversions and ground water withdrawals that have direct or seasonally significant impacts on stream flows
- Replace ground water withdrawals that may otherwise have a longer-term impact on stream flows
- Provide for future water demands with minimal or no impact to stream flows
- Mitigate impacts from future water demand by augmenting stream flow

The objectives for applying the direct injection with passive recovery method to locations in the Yakima River Basin include:

1. Offset current irrigation surface water withdrawals to improve stream flows and overall water supply reliability
2. Mitigation offset for future water municipal rights
3. Maintain and/or restore depleted aquifer storage to extend the sustainable yield of the aquifer
4. Increase ground water storage that may be used during emergency drought conditions
5. Create local salmonid refugia

The feasibility and benefits of direct injection were investigated for both municipal and non-municipal (regional) uses. The municipal ASR option looked at injection of treated water into the clastic Ellensburg formation and active and passive recovery for municipal uses and increases in stream flow. The regional ASR option looked at injection of treated water into the basalt formations and active recovery for irrigation uses.

Municipal ASR

Identified candidates that may benefit from municipal ASR include the cities of Yakima (Ahtanum Valley), Ellensburg (Kittitas Valley), Kennewick (Lower Valley), the Blackrock-Moxee Valley and in the Lower Yakima Valley immediately downstream of Union Gap. The analysis focused on the Ahtanum, Kittitas, and Blackrock-Moxee areas because the sites are upstream of the Parker gauge where the TWSA control point is established.

A three-dimensional ground water flow model was used for the Ahtanum-Moxee Sub-basin in the Yakima Valley to evaluate the potential for using ASR as a ground water management option. The goal of the model was to estimate the quantity of recharged water to three injection wells that would (a) return to the Yakima River, (b) discharge at other hydrologic sinks, and (c) remain in the subsurface in the form of increased ground water storage. The focus of the model was on seepage return flows to the Yakima River that result from direct injection to the deeper portions of the Ellensburg Formation. An analysis of active recovery was based on the increased aquifer storage. The model results were used to evaluate the Ahtanum, Kittitas, and Blackrock-Moxee sites.

Direct injection was simulated in the model to estimate the quantity of recharged water that discharged from the aquifer system to the Yakima River (thereby increasing flows) and to determine how much water remained in storage. The direct injection simulation included recharging water into the three wells for six months (i.e., October to March) at a constant rate of 2,000 gallons per minute (gpm) (4.46 cfs) each. Recharge ceased for the subsequent six months, and the cycle was repeated for nine years. The numerical computer simulation considered recharge at three wells, each at a rate of 2,000 gpm (total of 6,000 gpm) for six months (e.g., October through March) for an annual recharged volume of 4,800 AF. Application of the numerical computer simulation to specific sites extrapolates the simulation results to four wells, each at a rate of 2,000 gpm. The hydraulic responses are assumed to be linear, and are increased by a factor of 4:3 (1.33). Therefore, the total rate at each site is 8,000 gpm over six months to result in a recharge volume of 6,400 AF at each site.

The benefits of direct injection may be realized in several ways. Four end member scenarios are described, followed by one hybrid scenario:

1. Replacement of Current Surface Water Diversions: Replacing current municipal summer surface water diversions with ASR would result in a direct increase to stream flow during the 6-months from April to September. Recovery of 6,000 AF of ASR would improve TWSA initially by 6,000 AF. Yakima River flows would be additionally by augmented by between 0 to 1.2 cfs of seepage of injected water from the aquifer.

2. Pump and Dump: Direct discharge of ASR water to the Yakima River (i.e. "pump & dump") would increase Yakima River flows by 6,000 AF in the 6 months from April to September. This would also provide additional water quality benefits of clean, clear, cold water to the Yakima River, which is water quality impaired with respect to turbidity, temperature, and other parameters.

3. Satisfying Future Demand: Satisfying future demands with ASR would reduce demand pressure on the Yakima River by 6,000 AF. It would also increase Yakima River stream flows over current levels by the nonconsumptive portion withdrawal (i.e. return flows from wastewater treatment would essentially put a portion of the ASR storage directly back to the river). This would be on the order of 2,700 AF if used for City of Yakima municipal water supply (e.g., 45 percent nonconsumptive use from April through September).

4. Passive Recovery: Allowing injected water to seep back to the Yakima River would increase TWSA by a maximum of 50 percent of the annual injection rate. This would augment Yakima River flows by approximately 3,200 AF, assuming an annual inject rate of 6,400 AF. Only 50 percent of the injected volume contributes to TWSA because seepage is constant year-round, including 50 percent of the seepage volume during the irrigation season (April through September) and 50 percent of the seepage volume during the irrigation off-season (October through March).

5. Intermittent Active Recovery: One approach to using ground water storage is to only access or use stored ground water during water short years. Water stored during non water short years may be saved or banked for later use. Intermittent use would maximize the quantity of stored water for water short years because the recoverable amount of water is more than just what was stored in the most recent recharge season, and seepage rates to the Yakima River will be higher than if the injected water were recovered annually. For instance, direct injection during winter months for 10 years at a rate of 8,000 gpm (four wells at 2,000 gpm each) results in an increased aquifer storage of approximately 38,000 acre-feet and an estimated seepage rate of 5.2 cfs to the Yakima River (which presents a recharge scenario at rate of 6,000 gpm through three wells). Recovery of the additional stored water may require additional recovery wells.

The costs associated with a direct injection program include infrastructure associated with obtaining recharge water (e.g., surface water treatment facilities or river bank filtration (RBF) wells), transmission pipelines, injection wells, and additional costs (permitting, operations and maintenance, land acquisitions for facilities). The total cost for the direct injection sites with active recovery ranges from $18.2 million to $26 million for 6,000 AF of stream flow benefit from each site during April to September.

Regional ASR

The regional ASR alternative includes ASR for irrigation use and more extensive injection into the Columbia River Basalt Group aquifer system, rather than the clastic Ellensburg formation. Four areas were chosen to evaluate the feasibility of regional ASR (Kittitas, Roza, Tieton, and Toppenish) based primarily on the potential for use of the ASR system to provide irrigation water (rather than municipal) and on the presence of existing conveyance infrastructure (i.e., canals).

The basic concept is to capture large volumes of spring run-off prior to the irrigation season and store it in deep basalt aquifers that have a high recovery efficiency (i.e. low leakage and sufficient transmissivity to allow high volumes of injection and recovery). The basalts in the Yakima Basin are used for irrigation and a small amount of domestic supply and pumping is depleting these aquifers in some areas. These are conditions that have been shown to be favorable for ASR (e.g. Salem, Oregon), and ASR could "refill" some areas of the aquifer system.

Several large-scale wellfields using wells with high injection and recovery rates (on the order of 2,500 gpm per well) would be used for both injection and recovery. The water stored during the early spring would be pumped out during the summer and pumped into an existing and/or modified canal system. The wellfields could be operated year-after-year to increase the total water supply or only during dry or drought conditions to satisfy junior water rights.

The analysis evaluated the aquifer response to injection and storage from a wellfield injecting approximately 65,000 AF (2,500 gpm per well; 274 cfs per wellfield) over a 120 day period. Predicted water levels rises ranging from approximately 100 feet to 800 feet were predicted over the transmissivity and storage estimates incorporated into the final simulation, suggesting that for the conceptualized layout and injection quantities, regional ASR implementation is feasible within the basalt aquifers, provided that sufficient transmissivities, storativities, and suitable aquifer water levels can be demonstrated as part of more detailed design work.

Predicted water-level increases associated with ASR will vary in response to structural boundaries and can affect ultimate storage capacity. It is not possible to simulate these effects with existing data. If the cone of injection reaches a significantly higher transmissivity zone, then more storage may be attained with less associated head rise. Conversely, if the cone of depression reaches a structural boundary of lower transmissivity, higher head build up could limit storage capacity. Evaluation of the effects of hydraulic boundaries is a critical part of more detailed design analysis.

The costs are estimated to range from $3,000 to $6,000 dollars per acre-foot of water depending on the treatment option chosen. The lower $/acre-foot costs are associated with RBF as the preferred treatment method. The costs are very preliminary and subject to uncertainty because of the need to determine a preferred treatment approach. In addition, the costs for pumping associated with conveying RBF water to the ASR wellfields has not been determined.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS/ABBREVIATIONS

AF	acre feet
ASR	aquifer storage and recovery
CAP	Central Arizona Project
CRBG	Columbia River Basalt Group
cfs	cubic feet per second
DBP	disinfection by product
Decree	1945 Consent Decree
DEM	digital elevation model
Ecology	Washington State Department of Ecology
EES	Economic and Engineering Services
Final EIS	Final Environmental Impact Statement
ft	feet
ft^2	square feet
GIS	Geographic Information System
Golder	Golder Associates Inc.
gpm	gallons per minute
HAA	haloacetic acid
in/yr	inches per year
K	hydraulic conductivity
KAF	thousand acre feet
mi^2	square mile
mgd	million gallons per day
mg/L	milligrams per liter
msl	mean sea level
MVS/EVS	mining visualization system/environmental visualization system
NWIS	National Water Information System
O&M	operation and maintenance
OFM	Office of Financial Management
PRMS	Precipitation-Runoff Modeling System
RBF	river bank filtration
Reclamation	U.S. Bureau of Reclamation
SDF	stream depletion factor
SDWA	Safe Drinking Water Act
SOAC	Systems Operating Advisory Committee
TDS	total dissolved solids
THM	trihalomethanes
TSS	total suspended solids
TWSA	total water supply available
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WIP	Wapato Irrigation Project

WSDOH	Washington State Department of Health
WSDOT	Washington State Department of Transportation
WY	water year
YRBWEP	Yakima River Basin Water Enhancement Project

1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVE

The Washington State Department of Ecology (Ecology) is preparing a Final Environmental Impact Statement (Final EIS) to evaluate an Integrated Water Resource Management Alternative. The current water supply and storage capacity within the Yakima River Basin does not meet the water supply demands in all years and affects the Yakima River Basin's economy, which is agriculture-based. Water resources are also vital to the basin's aquatic resources—specifically those resources supporting anadromous fish. Ecology seeks to identify a means of increasing water supplies available for purposes of improving anadromous fish habitat and meeting irrigation and municipal needs. This report supports this effort and evaluates the feasibility of ground water storage alternatives as part of the state's alternatives analysis.

The ground water storage alternatives include surface recharge with passive recovery and direct injection with active and passive recovery. These alternatives include placing water in the aquifer system and storing it to realize benefits in the form of increased streamflow from increased ground water discharge, recovery of the stored water for out-of-stream uses, and/or replenishing depleted ground water storage. The ground water storage alternatives are conjunctive use tools in which the use of surface water and ground water can be coordinated to minimize impacts to the hydrologic system and provide environmental benefits.

Surface recharge with passive recovery involves diverting and infiltrating surface water into a recharge basin during periods of high streamflow and allowing it to discharge naturally back to a stream. The recharge basins are located so that the timing of return flow to a stream corresponds to periods of low flow. The water would be available for instream or out-of-stream uses when it reaches the stream.

Aquifer Storage and Recovery (ASR) is a specific application of artificial recharge in which water is recharged to an aquifer and stored for later recovery and use. Typically, ASR involves diverting water during times of higher availability, usually surface water during the winter and spring runoff season, and recharging it into aquifers that act as storage reservoirs. The stored water is then withdrawn during times of higher demand and lower availability. Conventional ASR projects operate on an annual cycle and withdraw during dry summer seasons. However, longer multiyear cycles may also be considered, such as recharging every year and only withdrawing during drought years.

Direct injection can also be used to store water in the aquifer with passive recovery. Potable water would still be injected into an aquifer during periods of excess capacity but the water would become part of the natural ground water system and remain in the aquifer and flow to its natural discharge areas (i.e., streams or springs). The water would be passively recovered when it reaches the stream and is available for instream or out-of-stream uses.

1.2 BACKGROUND

The Yakima Basin is located in eastern Washington (Figure 1-1). The following description of the Yakima Basin is from the U.S. Bureau of Reclamation's (Reclamation) Interim Comprehensive Basin Operating Plan for the Yakima project (Reclamation, 2002). Elevations range from 8,184 feet in the Cascades to 340 feet at the mouth of the Yakima River. The Yakima River flows for about 215 miles. Its major tributaries include the Naches, Kachess, Cle Elum, and Teanaway Rivers in the upper basin (above Yakima), and Toppenish and Satus Creeks in the lower basin. Timber, cattle, fish and wildlife habitat, and recreation are the major uses of the northern and western areas of the basin, while irrigated agriculture is the main economy of the lower basin. Climate ranges from alpine to arid, with precipitation varying from 140 inches annually in the Cascades to less than 10 inches in the Kennewick area (Reclamation, 2002).

The Yakima Project was authorized by Congress in 1905 to increase the storage capacity within the basin. Development of the Yakima Project progressed with the construction of Bumping Dam (1910), Kachess Dam (1912), Clear Creek Dam (1914), Keechelus Dam (1917), Tieton Dam (Rimrock Lake, 1925), and Cle Elum Dam (1933). These six federal reservoirs have a total storage capacity of 1,070,000 acre-feet (AF) and provide the water supply necessary to help meet the irrigation and instream flow needs by storing and regulating a portion of the flow of the Yakima River and its tributaries. Other principal features of the Yakima Project include several diversion dams, two hydroelectric generating plants, and numerous canals, laterals, and pumping plants (Reclamation, 2002).

During years of low runoff, disputes began over water use in the basin. In 1945, the District Court of Eastern Washington issued the 1945 Consent Decree (Decree), which established the rules under which Reclamation should operate the Yakima Project. The Decree determined the quantities of water to which all project users are entitled, and defines a prioritization for water-short years. Users were divided into two classes, nonproratable (those with the most senior rights) and proratable. Nonproratable users are served first from the total water supply available (TWSA) and proratable users share equally in the balance of available supply (Reclamation, 2002).

Since 1945, the courts have issued numerous other decisions in the Yakima Basin Adjudication related to protection of fish resources, the rights of the Yakama Nation, return flows, ground water, abandonment of claims, and flood water use.

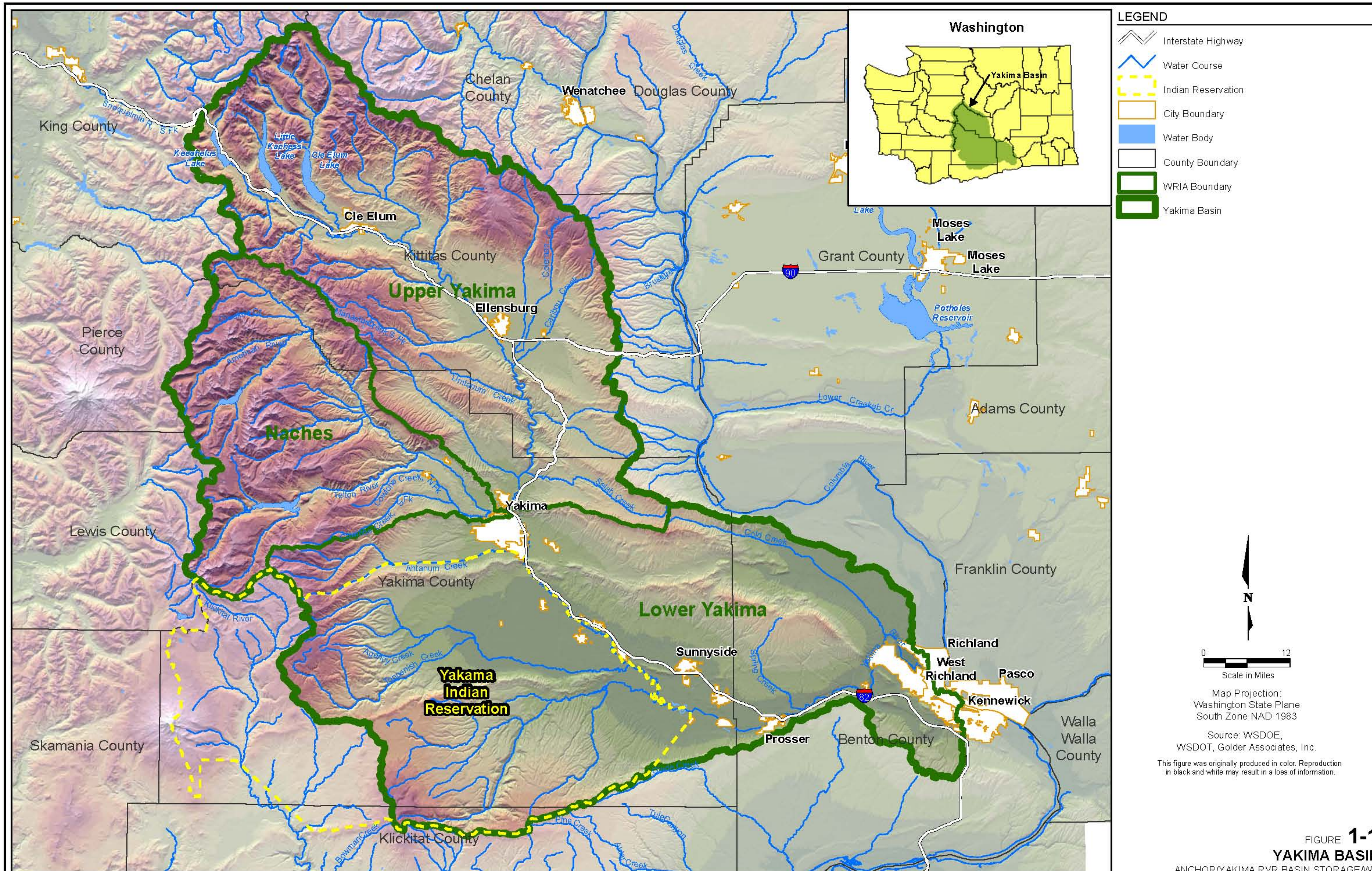

FIGURE 1-1
YAKIMA BASIN

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1.3 DOCUMENT ORGANIZATION

This technical report is divided into the following sections:

- Section 1.0: Introduction
- Section 2.0: Description of Ground Water Storage Alternatives
- Section 3.0: Background
- Section 4.0: Surface Recharge with Passive Recovery
- Section 5.0: Direct Injection: Municipal ASR
- Section 6.0: Direct Injection: Regional ASR
- Section 7.0: References

Section 2 describes the ground water storage alternatives and is related to the project description in the Final EIS. Section 3 provides background information on the project areas, surface water flows, water demands and water management within the Yakima River Basin, and hydrogeologic characteristics of the basin. Section 4 contains the methods, analysis, and results of the surface recharge alternative. Section 5 contains the methods, analysis, and results of the municipal ASR alternative. Section 6 contains the methods, analysis, and results of the regional ASR alternative. The information in Sections 4, 5, and 6 can be used to describe the affected environment and can be used to identify potential impacts from ground water storage for the Final EIS.

2.0 DESCRIPTION OF GROUND WATER STORAGE ALTERNATIVES

The ground water storage alternative includes using the natural storage capacity of geological formations in both the confined (i.e., deep) and unconfined (i.e., water table) portions of the aquifer system. The approach includes recharging water (placing water in) the aquifer system and storing it to realize benefits in the form of increased streamflow from increased ground water discharge, recovery of the stored water for out-of-stream uses, and/or replenishing depleted ground water storage.

Aquifers provide a natural storage reservoir that can be used to store the water available under an existing water right. Water available during off-peak times can be stored in an aquifer and recovered to supply peak demands. Aquifer storage can also augment stream flows during peak demand periods through increased ground water discharge of the water stored during off-peak periods. Thus, ground water storage can provide a more reliable water source or increase stream baseflow during critical times. The geological formations targeted for ground water storage include the following:

- Shallow alluvium and unconsolidated sediments
- Basin fill sedimentary rock (e.g., Ellensburg Formation)
- Basalts

Ground water storage is achieved by recharging water to the deep and shallow portions of the aquifer system (i.e., confined and unconfined). There are two distinct methods of recharge:

- <u>Direct Injection</u>. This method injects water via wells and targets deeper confined aquifers.
- <u>Surface Infiltration</u>. This method distributes water at the ground surface, which then infiltrates to a shallow, unconfined aquifer.

The two recharge methods are sufficiently different in terms of technology, impacts, and costs; therefore, they are considered as separate ground water storage alternatives in the EIS.

The source water is expected to be surface water from either the Yakima River or one of its tributaries. New or existing infrastructure (canals or pipelines) would be used to convey this water to the recharge site. The availability of water will be a function of seasonal timing and location within the Yakima River Basin.

2.1 INJECTION RECHARGE

Injection recharge is a method that injects water via wells into a deep subsurface geologic formation. The injected water may or may not be recovered, depending on the objective of the recharge. ASR is the term used when the stored ground water is actively recovered for potable (municipal) or nonpotable uses. When the storage is allowed to discharge naturally, it is called injection with passive recovery.

2.1.1 Aquifer Storage and Recovery

ASR systems inject water via wells into aquifers during periods of excess capacity and withdraw the water during periods of peak demand or limited supply. In Washington State, ASR systems are regulated under Washington Administrative Code (WAC) 173-157. Figure 2-1 shows a typical configuration of an ASR system. The source water must be of high quality (i.e., near-potable quality) for operational purposes (i.e., to prevent well clogging by sediment and biological growth) to meet state regulations that protect ground water quality, and to better ensure potable quality when recovered (if used for municipal water supply). Water of such quality may be obtained from conventional drinking water treatment plants, or from ground water wells (e.g., shallow alluvial wells in close hydraulic continuity with surface water – this configuration is also referred to as river bank filtration [RBF]).

The water is injected directly into an aquifer (usually confined), and the stored water is actively recovered for potable or nonpotable supply using the same or other wells. ASR systems require recharge/recovery wells and conveyance infrastructure to transport the water from the source to the recharge well and from the recovery well to the municipal supply or augmentation location. ASR systems are an established and well-regulated management technique for water systems with appropriate source water and infrastructure configurations.

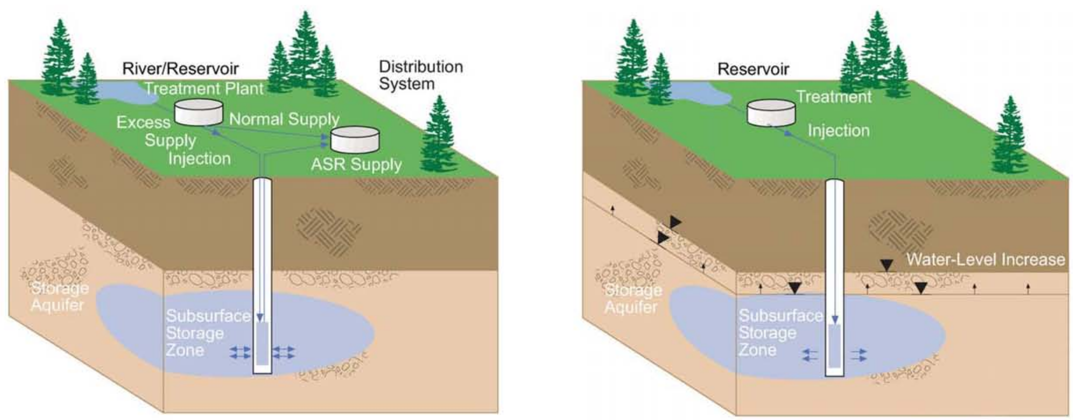
The hydrogeology of an area is an important factor in locating recharge sites. The aquifer must have suitable hydraulic properties and, in some cases, favorable hydraulic boundaries to ensure that the stored water can be efficiently recovered and not lost to streams or captured by other water users. This is why the ASR alternative in the Yakima River Basin targets deeper aquifers in the Ellensburg Formation or basalts. Water that is not actively recovered may remain in the aquifer or seep back to streams. This can improve ground water levels locally and may improve baseflow to surface waters in hydraulic connection with deeper geologic formations. The objectives for applying the municipal ASR or regional ASR approaches include the following:

1. Offset current and future municipal or irrigation surface water withdrawals to seasonally improve streamflows and overall water supply efficiency

2. Improve reliability of peak and long-term water supply

3. Recover deeper ground water levels and baseflow discharge over the long term

4. Provide the potential capability for storage of reclaimed water



Municipal Aquifer Storage and Recovery (ASR)

Injection with No Recovery

FIGURE **2-1**
INJECTION RECHARGE
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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The first objective, offsetting municipal or irrigation surface water withdrawals, would be achieved by diverting water under a municipal water right during off-peak demand periods or an irrigation water right and injecting it into an aquifer. The water would then be actively recovered during peak demand periods and thereby reduce the surface water demand during that period. Peak municipal and irrigation demands are generally during the summer months when streamflows are lower, so this method would improve surface water supply by decreasing the impacts to streams during the summer. Storing water in aquifers would also reduce evaporation losses compared to losses that would be expected if the water were stored in a surface reservoir.

The second objective, improving the reliability of the peak and long-term supply, would be achieved in the same way as the first objective; however, the recovery of the water would be postponed until the municipal demand exceeds the current supply or there is a drought that results in irrigation demands not being met. The long-term storage and recovery of the water will also enable the municipality to meet future peak demands. The long-term supply for non-municipal uses could also be improved through active recovery of the injected water for streamflow augmentation during dry or drought water years to improve TWSA.

The third objective, improving ground water conditions over the long-term, would be achieved based on the long-term annual ratio between injection storage and recovery. Water that is left in the aquifer and not actively recovered would, over the long term, become part of the natural ground water system.

The fourth objective, storing reclaimed water, would be achieved by injecting reclaimed water (treated to the necessary standards) into an aquifer and allowing direct recovery of the water for future municipal or irrigation use. This approach would make efficient use of the water use under an existing water right because it would put the water into a reclaim and reuse cycle that would offset a portion of future municipal or irrigation demands from the stream.

2.1.1.1 General Requirements

The feasibility of ASR for municipal or non-potable (irrigation) purposes depends on water quality, infrastructure, costs, permitting, hydrogeology, a suitable recharge water source, and customer acceptance (aesthetic parameters associated with water quality). A summary of these considerations is presented below.

Water Quality: Water quality concerns for an ASR project relate to human health and operational considerations. An ASR project used to supply municipal drinking water must meet federal (Safe Drinking Water Act [SDWA]) and Washington State Department of Health [WSDOH], WAC 246-290) drinking water standards. Any reactions between the recharged water and the native ground water and aquifer mass must result in concentrations of regulated parameters that meet drinking water standards, if used for drinking water purposes.

Operational water quality concerns include biological growth, mineral precipitation and dissolution, and corrosion of the well screen. Bacterial growth and mineral precipitation (which is often catalyzed by bacteria) can cause clogging of the well screen. Problems related to mineral dissolution are more likely associated with meeting drinking water standards (e.g., dissolution of sulfide minerals may release heavy metals). In extreme, but unlikely, cases, dissolution of minerals may cause aquifer stability formation problems around the well screen.

Infrastructure: Suitable infrastructure for ASR must be available or constructed, possibly including facilities for the treatment of surface water used for direct injection, a distribution system from the source of recharge water (e.g., streams) to recharge sites, and wells suitable for ASR (i.e., recharge and recovery wells). Treatment of surface water is needed for two reasons: 1) to ensure low total suspended sediments that may otherwise clog an ASR well, and 2) to reduce pathogens that may be present in surface water for the protection of human health.

The cost of obtaining water of the desired quality for direct injection can be reduced relative to surface water treatment plants by using RBF methods. RBF methods include withdrawing ground water from wells in close hydraulic continuity with surface water. This method uses the natural filtration capacity of sediments to filter total suspended solids and pathogens that may be present.

Costs: The cost of ASR must be favorable in comparison to other water management strategies. A higher cost for ASR relative to other water management or storage strategies may be acceptable if there is a net environmental benefit or other enhancement. Generally, the costs of an ASR program benefit from scales of economy (i.e., the larger the project, the lower the unit cost of providing the water). Under certain conditions, cost is a minimal concern if no other feasible alternative is available (e.g., water rights are not available because of the seasonal impacts of water use on stream flows or limited ground water availability).

Permitting: ASR is a water resource management tool that is explicitly endorsed by Washington State. Numerous regulations must be complied with and permits obtained for an ASR project. These regulations are intended to ensure the protection of human and environmental health. A valid ASR project should be able to adequately comply with these regulations and permitting requirements without significant effort. The following is a list of the primary applicable regulations:

- Water Rights (RCW 90.03 and 90.44)
- ASR (WAC 173-157)
- Well Construction (WAC 173-160)
- Water Quality (WAC 173-200)
- Underground Injection Control Program (WAC 173-218)
- WSDOH (WAC 246-290)

The water recovered in an ASR program for potable use has to meet drinking water standards. Water rights also have to be available. Water may be more available for ASR permits than for conventional water right permits that involve year-round uses because the diversion of water for storage in an ASR program typically occurs during the off-season or rainy season.

Hydrogeology: A favorable hydrogeological setting for ASR is one that retains the recharged water for later recovery (e.g., a well-confined system that limits the loss of water from the system), and an aquifer that is sufficiently permeable to avoid excessive build-up of head at the injection well.

Recharge Water Source: A source of high-quality recharge water is required. The water must effectively meet drinking water standards in order to meet the regulatory standards of WAC 173-200 (Protection of Ground Water Quality). It should also be chemically compatible with the native ground water and aquifer mass; otherwise, the aquifer may need conditioning by multiple flushing cycles.

Customer Acceptance: The water that is recovered and furnished to drinking water customers has to be acceptable from aesthetic standpoints (e.g., taste and odor). Customers are usually accustomed to a particular “flavor” of water. Changes of any kind typically elicit questions of concern from customers. Although these changes may be of no health concern (e.g., temperature) or of variable health concern (e.g., increased calcium concentrations although not regulated for drinking water may contribute to gall stone formation or mitigate osteoporosis), such changes must be satisfactorily addressed in order to ensure public acceptance.

2.1.2 Injection with Passive Recovery

Direct injection can also be used to store water in the aquifer with passive recovery (Figure 2-1). Potable water would still be injected into an aquifer during periods of excess capacity but the water would become part of the natural ground water system and flow to its natural discharge areas (i.e., streams or springs). The water would be passively recovered when it reaches the stream and is available for instream or out-of-stream uses. Injection into a deep aquifer results in a longer lag time between injection and when the water reaches its natural discharge areas. This interannual retention time provides a more constant discharge of recharged water to streams and other discharge areas. Injection to shallower portions of the aquifer system will provide shorter lag times between the time of recharge and the time of peak return flows.

Direct injection with passive recovery requires a high-quality water source (as described in Section 2.1.1.1), recharge wells, and conveyance infrastructure to transport the water from the source to the well. The system would still be subject to WAC 173-157 because water is being injected into an aquifer.

The siting of this type of injection system is different than a typical ASR system. Areas would be targeted that have hydraulic continuity between the aquifer and natural discharge areas that would benefit from increased baseflow. Areas where ground water has been depleted or mined through heavy use could also be targeted to restore water levels. For both purposes, the benefits would be realized over a long period of time and distributed over a relatively large area.

The objectives for applying the direct injection with passive recovery method to locations in the Yakima River Basin include the following:

1. Offset current irrigation surface water withdrawals to improve streamflows and overall water supply reliability

2. Mitigation offset for future municipal water rights

3. Maintain or restore depleted aquifer storage to extend the sustainable yield of the aquifer

4. Increase ground water storage that may be used during emergency drought conditions

5. Create local salmonid refugia

The first objective, offsetting current irrigation surface water withdrawals, is targeted for areas that have experienced, or may experience, significant ground water level declines due to a large ground water demand. If an aquifer is in hydraulic continuity with a stream, then it is possible that the ground water level decline may be currently impacting surface discharges, such as streams or springs. Injection recharge could reduce current impacts of ground water use on the stream over the long term. Maintaining or raising ground water levels could reduce pumping costs and extend the life of existing wells.

The second objective, mitigating future water rights, is intended to provide an option for one or more municipalities to inject water into an aquifer to mitigate for the impacts of a future surface or ground water withdrawal needed to support growth. This form of mitigation would require a system designed to recharge the same body of water (aquifer) from which the withdrawal is occurring, and would need to raise or maintain ground water levels so that other ground water users are not impaired. The source water would still be obtained during times of off-peak demand. It may be appropriate for groups of two or more entities requiring water to jointly develop the mitigation near their proposed withdrawals.

The third objective, restoring depleted aquifer storage to extend the sustainable yield of the aquifer, is intended to replenish ground water storage where it has been depleted by historical pumping of ground water. In such areas, ground water withdrawals are greater than natural recharge rates and ground water levels have dropped by up to several hundred feet. This has resulted in ground water users having to deepen wells and pay greater pumping costs as greater head lifts are needed. Increasing the recharge of the aquifer may slow or arrest the rate of decrease of ground water levels, and possibly replenish depleted ground water storage.

The fourth objective, increasing ground water storage that may be used during emergency drought conditions, is similar to the third objective. Temporary emergency drought wells are often permitted during drought years. However, issuance of such permits still requires nonimpairment on other ground water users. Therefore, increasing the available ground water storage will provide additional storage to supply temporary drought permits for ground water withdrawal.

The fifth objective, creating local salmonid refugia, is intended to facilitate salmonid migration and improve spawning grounds. Cold ground water seeps to streams often provide refugia for migrating salmon and are the locations of spawning. Ground water seeps are often associated with geological structures, such as faults or fold structures. Recharge of cold surface water during the winter at certain geologic structures may increase the flux of cold water to streams at existing areas of ground water discharge and salmonid refugia.

2.1.2.1 General Requirements

The general requirements for injection with passive recovery are the same as those required for ASR with the exception of the hydrogeology. The general requirements for ASR are discussed in Section 2.1.1.1. The hydrogeology requirements for injection with passive recovery are different from ASR because the objective is to have the injected water naturally discharge back to a stream over time. This requires a hydraulic connection between the hydrogeologic unit targeted for injection and a stream. The aquifer still needs to be moderately to highly permeable to accept the recharge water within excessive build-up of head. The native ground water and aquifer mass should also be chemically compatible with the recharge water to prevent changes in the stored water quality or precipitation of minerals that could clog the well or aquifer.

2.2 SURFACE RECHARGE WITH PASSIVE RECOVERY

Surface recharge with passive recovery involves diverting and infiltrating surface water into a recharge basin during periods of high stream flow and allowing it to discharge naturally back to a stream (Figure 2-2). The natural discharge back to the stream is termed passive recovery because the water is available for instream and out-of-stream uses when it reaches the stream. The infiltration sites are located so that the timing of return flow to a stream corresponds to periods of low flow. The source of the infiltration water would be a direct surface diversion from a river or irrigation canal, or suitably high-quality reclaimed water. The infiltration system recharges water before lower stream flow conditions occur. Pumping or other infrastructure may be required to move water from the source to the infiltration basin.

Using surface recharge to augment stream flows requires a good understanding of stream-aquifer interaction to effectively manipulate the timing of return flows to benefit the stream. The effectiveness of surface recharge is dependent on the properties of the aquifer system (e.g., storativity and transmissivity), and is targeted for shallow alluvium and unconsolidated sediments in the Yakima River Basin.

The objectives for applying the surface recharge (passive recovery) method to locations in the Yakima River Basin include the following:

1. Offset impacts of current irrigation surface water withdrawals on streamflows

2. Improve reliability for certain agricultural water demands during water short years by increasing TWSA

3. Provide capability for surface application and storage of reclaimed water

The first objective, offsetting current irrigation surface water withdrawals, would be achieved by increasing the magnitude of return flows during the irrigation season.

The second objective, improving reliability for certain agricultural water demands, would also be achieved by increasing the magnitude of return flows during the irrigation season. Higher stream flows could improve the reliability of supply to junior water right holders because irrigation deliveries are managed by stream flow levels at various control points along the Yakima River. In addition, surface recharge could return to irrigation canals.

The third objective, storing reclaimed water, is a longer term objective that would infiltrate municipal reclaimed water if and when suitable infrastructure is developed to handle a reclaimed water system.

2.2.1 General Requirements

The feasibility of surface infiltration depends on infrastructure, costs, permitting, hydrogeology, a suitable recharge water source, and the timing of return flows to the river.

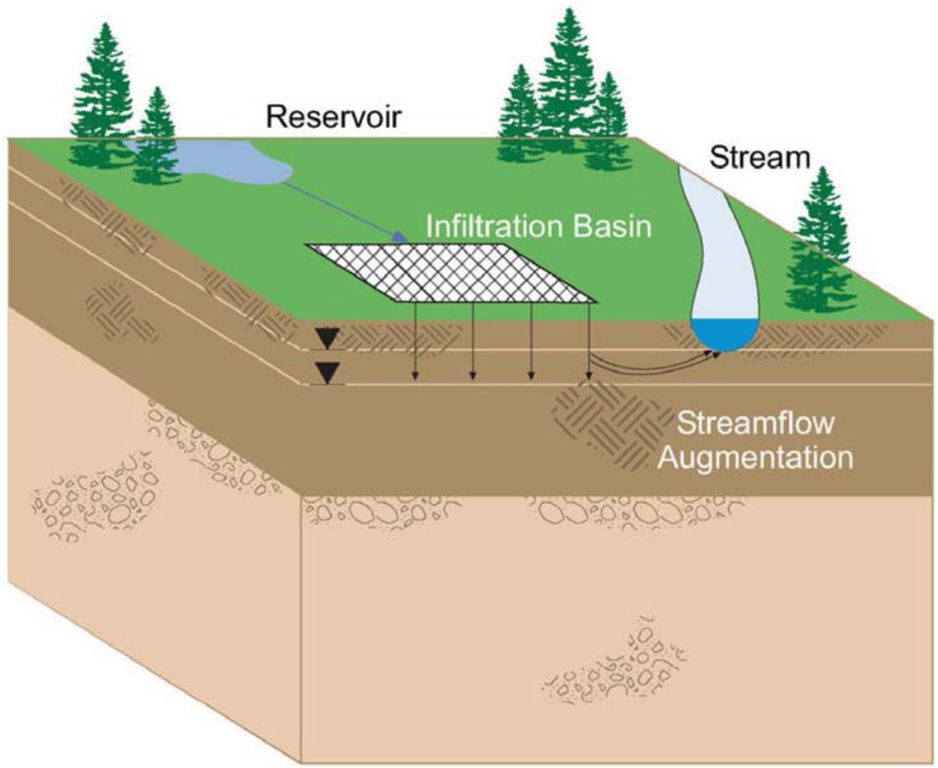
Infrastructure: Suitable infrastructure for surface infiltration must be available, including a distribution system from the source of recharge water to the infiltration facility sites.

Costs: The cost of surface infiltration must be favorable in comparison to other water management strategies. A higher cost for surface infiltration relative to other water management of storage strategies may be acceptable if there is a net environmental benefit or other enhancement. The costs for surface infiltration include infrastructure and leasing or purchase costs for the land needed to site infiltration facilities. Close proximity to sources of water from infrastructure such as canals and ditches will reduce infrastructure costs.

Permitting: Water rights have to be available for a supply of recharge water. There are other water right and permitting issues that are currently ambiguous in the state of Washington, but these are currently being addressed in the rulemaking process for ASR.

Surficial Geology/Hydrogeology: Surface infiltration requires geologic units that provide sufficient infiltration and permeability capabilities. Areas with alluvium or unconsolidated sediments at the ground surface are favorable for surface infiltration. The hydrogeology of the aquifer system should be favorable for surface infiltration and passive recovery, including a shallow unconfined aquifer system that is hydraulically connected to a stream.

Recharge Water Source: A source of recharge water is required. Surface infiltration also requires close proximity to sources of water from infrastructure such as canals and ditches. The native ground water and aquifer mass should be chemically compatible with the recharge water to prevent changes in the ground water quality. Source water is typically surface water.



Surface Infiltration with No Recovery

FIGURE **2-2**
SURFACE RECHARGE
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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3.0 BACKGROUND

This section describes the project areas, stream flows, surface water management control points, water demand, and hydrogeology of the Yakima River Basin. Ground water storage projects must fit within the existing structure of water management within the basin. Projects are also limited to areas with suitable hydrogeology. A brief overview of the physical and legal framework within the Yakima River Basin is provided in this section.

3.1 PROJECT AREAS, STREAM FLOWS AND CONTROL POINTS

The suitability of project locations within the Yakima River Basin is influenced by the geology/hydrogeology, surface water flows, surface water control points, and the location of the existing canal network.

3.1.1 Sub-Basins

The Yakima River Basin is a 6,200 square mile (mi^2) area in south-central Washington. The basin contains three ecoregions: Cascades, Eastern Cascades, and Columbia Basin (Jones, et al., 2006). Tributaries to the Yakima River include eight major rivers and numerous smaller streams. The largest tributary to the Yakima River is the Naches River.

Six smaller structural basins, created by large east-west anticlinal ridges, were identified within the Yakima River Basin as part of a U.S. Geological Survey (USGS) study (Jones, et al., 2006). The sub-basins consist of broad, flat-bottomed valleys that slope gently towards the Yakima River. From the headwaters of the Yakima River, the basins are Roslyn, Kittitas, Selah, Yakima, Toppenish, and Benton (Figure 3-1). Figure 3-2 shows the geology of the Yakima River Basin, highlighting five of the six sub-basins which contain unconsolidated hydrogeologic materials.

3.1.2 Stream Flows and Control Points

The USGS records stream flow of the Yakima and Naches rivers (Figure 3-2). The average yearly runoff at key locations with the basin is provided in Table 3-1. The average annual measured flow volume at the Parker gauge is 1,563,216 AF. There are regulated and unregulated flows within the basin. Regulated flows represent releases from the reservoirs. Unregulated flows are primarily driven by snowmelt during the irrigation season (Mastin, 2008). The stream flow measured at any given location in the Yakima Basin is a combination of regulated and unregulated flows. Mean annual regulated flows total 3,600 cubic feet per second (cfs) (about 2.6 million AF) and mean annual unregulated flows total 5,600 cfs (about 4.1 million AF) (Mastin, 2008).

An evaluation of the potential impacts of climate change on unregulated stream flow indicated that there would be changes in the seasonal distribution of runoff with more runoff occurring in the late autumn and winter months and less occurring in the late spring and summer (Mastin, 2008). The simulated decrease in snowpack in the spring results in less runoff in the summer months because of the dependence of the Yakima Basin on snowmelt for summer flows (Mastin, 2008).

The Yakima River at Cle Elum, Naches River near Naches, and Yakima River at Parker gauges are used as TWSA control points. The TWSA, as interpreted by Reclamation, is "…the total water supply available for the Yakima River basin above [the Parker gauge] PARW, for the period April through September" (Reclamation, 2002). Therefore, the Parker gauge is the primary control point that influences the amount of water available for water right holders in the Yakima River Basin.

Stream flow temperatures in the Yakima River basin were measured in 2001 and 2002 for eleven reaches (Vaccaro, et al, 2008). Temperatures in the Thorp reach near Ellensburg ranged from 15.0 to 15.94 degrees Celsius in the northern part of the reach and from 15.94 to 16.85 degrees Celsius in the southern part of the reach near Ellensburg on September 25, 2002. Temperatures in the Naches near Naches River reach increased by about 6 degrees Celsius from Naches (minimum 14.24 degrees Celsius) to Brace (maximum of 20.74 degrees Celsius) on August 1, 2001. Low stream flow temperatures in the summer months indicate potential areas of ground water discharge and potential preferred salmonid habitat and thermal refugia.

3.1.3 Irrigation Canal System

There are over 50 irrigation districts that have an entitlement to divert water above the Parker gauge; the Kennewick Irrigation District diverts water below the Parker gauge (Reclamation, 2002). Irrigation water is delivered to land within an irrigation district via irrigation canals and ditches. The Yakima Basin Project supplies water to 465,000 irrigated acres of land. The water is delivered to seven divisions according to supplemental water supply contracts: Kittitas (59,123 acres), Tieton (27,271 acres), Sunnyside (103,562 acres), Roza (72,511 acres), Kennewick (19,171 acres), Wapato (136,000 acres), and supplemental water supply contracts (over 45,000 acres) (Reclamation, 2002). The water is delivered using an extensive canal system. The locations of canals in the Yakima River Basin are displayed on Figure 3-3.

TABLE 3-1

Average Yearly Runoff at Key Locations

Site	Average Yearly Runoff (AF per Year)	
	1961-1990 estimated unregulated flow[2]	1961 - 1990 measured flow[3]
Yakima River near Easton	651,000	342,215
Yakima River at Cle Elum[1]	1,478,000	1,183,648
Yakima River at Umtanum	2,007,000	1,750,128
Naches River near Naches[1]	1,234,000	838,606*
Yakima River at Parker[1]	3,410,000	1,563,216
Yakima River at Kiona	3,970,000	2,475,950

Notes:

1. Total Water Supply Available (TWSA) control point.
2. Reclamation Surface Water Hydrology Model.
3. Reclamation records.

*Wapatox Power Plant diverts 257,350 AF per year upstream of gauge.

Source: Reclamation (2002)

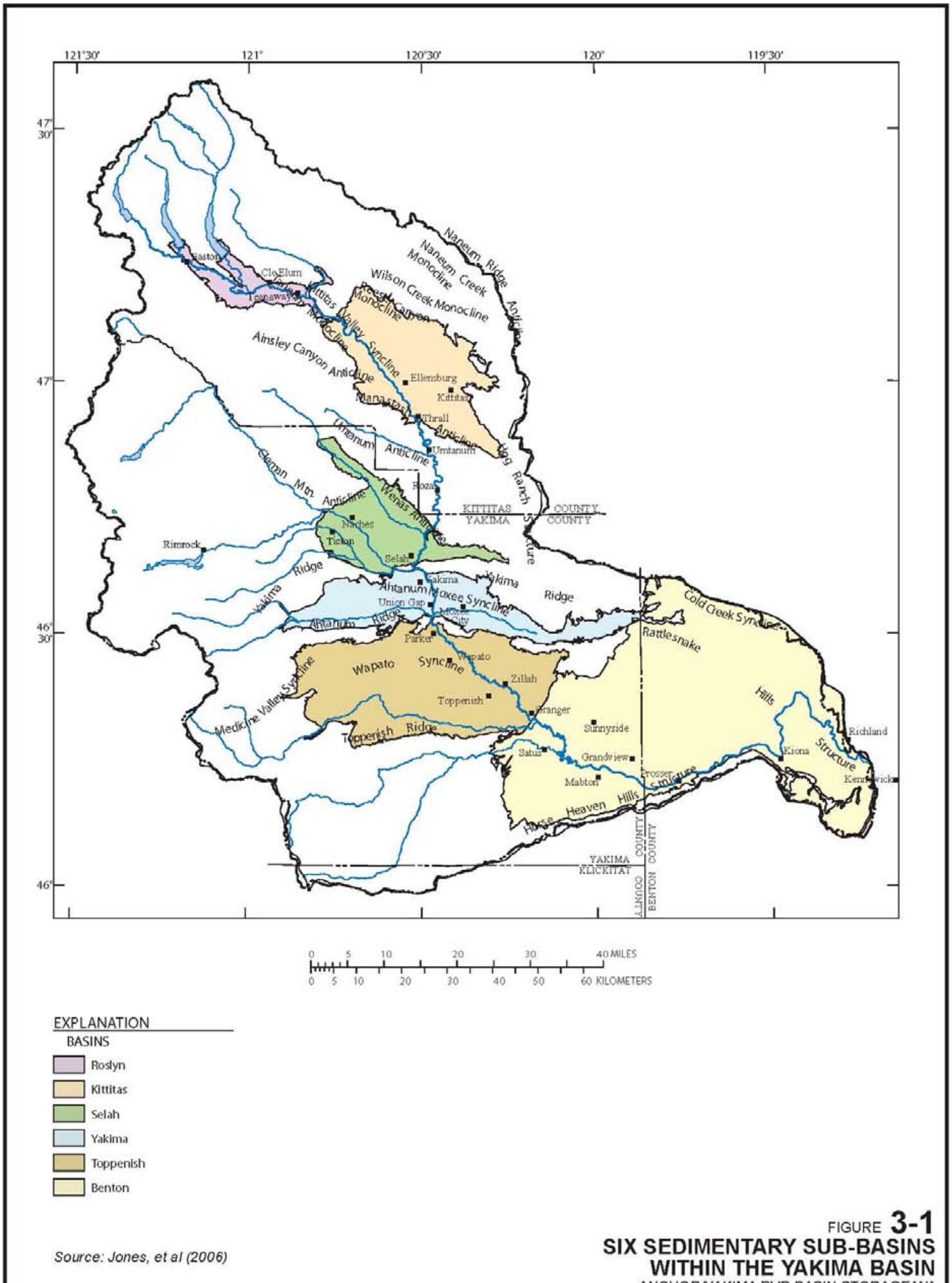

FIGURE 3-1
SIX SEDIMENTARY SUB-BASINS WITHIN THE YAKIMA BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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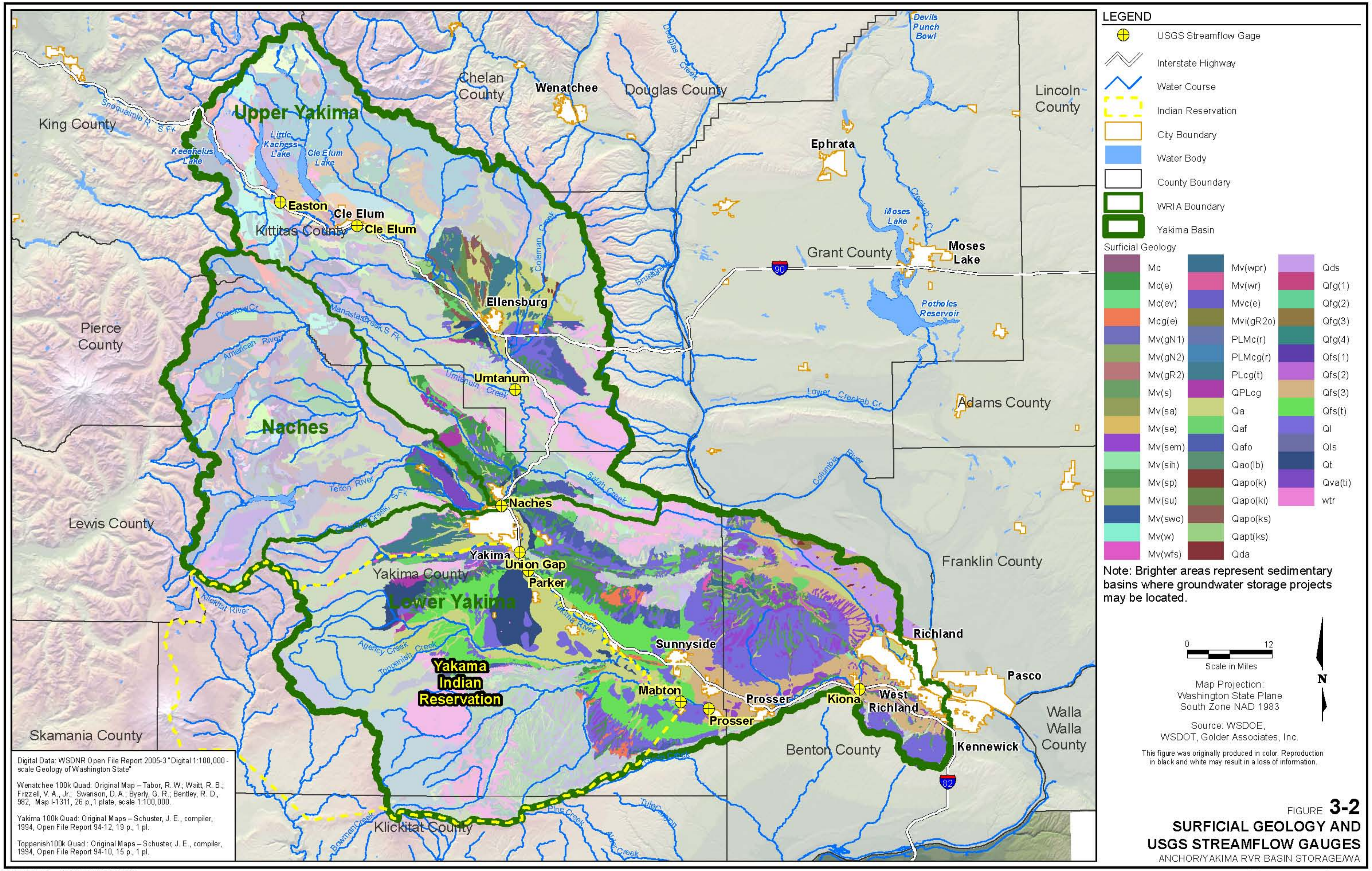

FIGURE 3-2
SURFICIAL GEOLOGY AND USGS STREAMFLOW GAUGES

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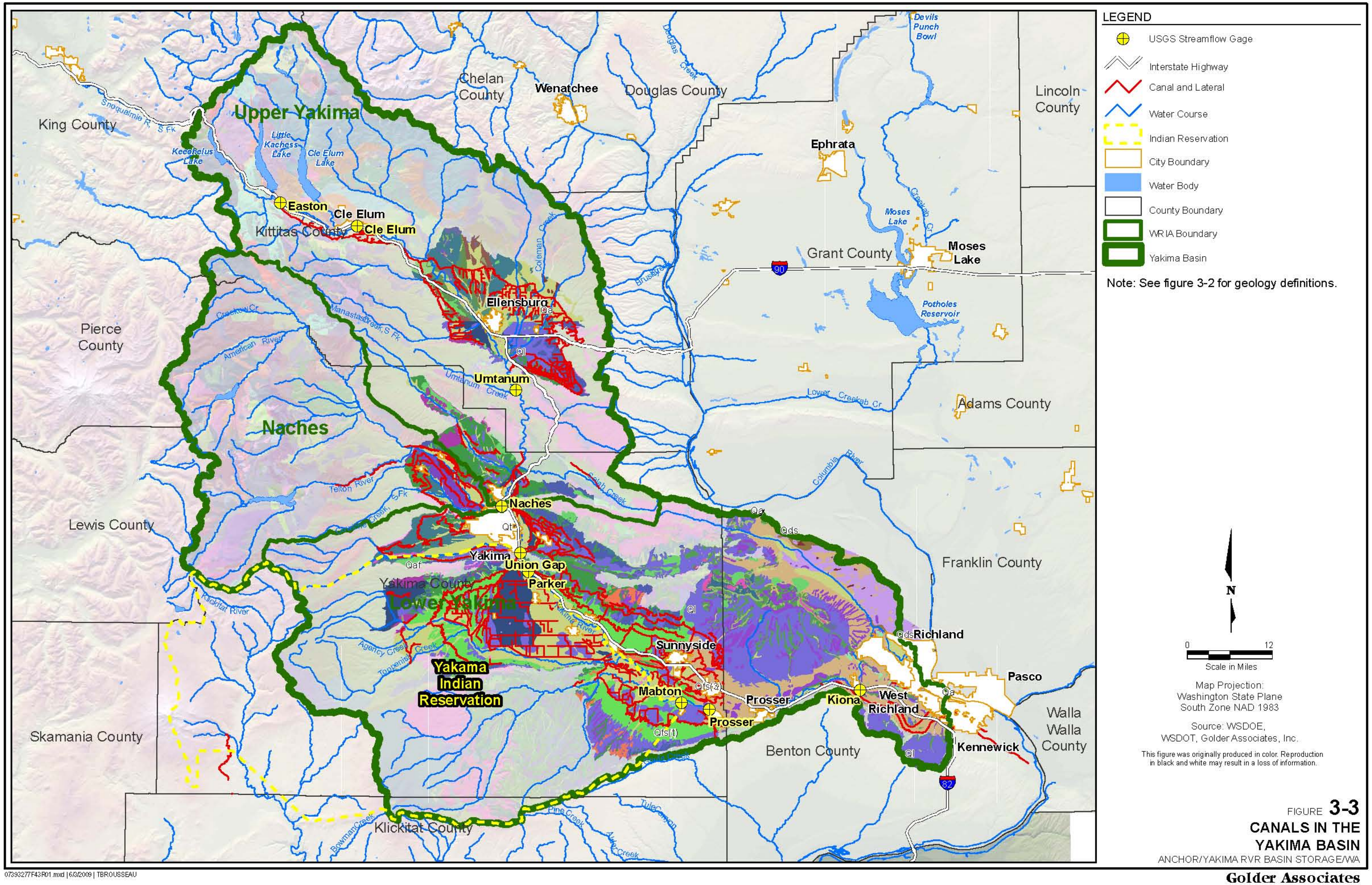
LEGEND
USGS Streamflow Gage
Interstate Highway
Canal and Lateral
Water Course
Indian Reservation
City Boundary
Water Body
County Boundary
WRIA Boundary
Yakima Basin
Note: See figure 3-2 for geology definitions.
Upper Yakima
Naches
Lower Yakima
Yakama Indian Reservation
King County
Pierce County
Lewis County
Skamania County
Klickitat County
Yakima County
Kittitas County
Chelan County
Douglas County
Grant County
Lincoln County
Adams County
Franklin County
Benton County
Walla Walla County
Wenatchee
Ephrata
Moses Lake
Ellensburg
Easton
Cle Elum
Umtanum
Naches
Yakima
Union Gap
Parker
Sunnyside
Mabton
Prosser
Kiona
West Richland
Richland
Pasco
Kennewick
Scale in Miles
Map Projection: Washington State Plane South Zone NAD 1983
Source: WSDOE, WSDOT, Golder Associates, Inc.
This figure was originally produced in color. Reproduction in black and white may result in a loss of information.
FIGURE 3-3
CANALS IN THE YAKIMA BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates

3.2 WATER DEMAND

The existing demand for water in the basin includes instream flows, irrigation demand, and municipal demand. Water available to supply the demand is limited by the total water supply available at the Parker gauge.

3.2.1 Instream Flow Demand

The following discussion on instream flow requirements is from the 2003 Yakima Basin Watershed Plan (EES, et al., 2003). Instream flow requirements are based on court orders and federal legislation related to the Yakima Irrigation Project. The requirements include target flows mandated by Congress and Reclamation's instream target flows at various reaches in the river system. The state of Washington has not established minimum instream flows in the Yakima River Basin (EES, et al., 2003).

Target instream flows have been defined at two points in the Yakima River Basin, as mandated by Congress through the Yakima River Basin Water Enhancement Project (YRBWEP) (Title XII of the Act of October 31, 1994, U.S. Congress [Public Law 103-434]). The legislation states that the Yakima project superintendent shall estimate the water supply which is anticipated to be available to meet water entitlements, and provide instream flows in accordance with the criteria in Table 3-2. This new operational regime was institutionalized in 1995 but initiated by the Yakima project superintendent in 1992 before passage of the Title XII legislation. The target flows cover the months of April through September (irrigation season), but do not define flows for the remaining months of the year. Operational target flows for other times of year and locations are set by Reclamation in consultation with the Systems Operating Advisory Committee. Those operational target flows are negotiated annually and are based on biological needs of fisheries (EES, et al., 2003).

Target flows are defined in a way that requires they be increased as water conservation elements of YRBWEP are implemented over time. Table 3-2 displays the target flows at this time, without implementation of conservation elements; and what they would be if the conservation goals of YRBWEP were fully met (EES, et al., 2003).

3.2.2 Proratable Irrigation Demand

The following description of water delivery entitlements is from Reclamation's Interim Comprehensive Basin Operating Plan for the Yakima project (Reclamation, 2002). Water delivery entitlements for all major irrigation systems in the Yakima River Basin, except for the lower reaches of the Yakima River near the confluence with the Columbia River, were determined in the Decree. The Decree states the quantities of water to which all project water users are entitled (maximum monthly and annual diversion limits) and defines a method of prioritization to be placed into effect during water-deficient years. The water entitlements are divided into two classes: nonproratable and proratable. Nonproratable entitlements are held by those water users with the earliest filed water rights, and these entitlements are to be served first from the TWSA. All other project water rights are proratable. They are of equal priority to each other, but second in line to the nonproratables. Any shortages that may occur are shared equally by the proratable water users (Reclamation, 2002). Flows at the Parker gauge control the amount of water available for nonproratable and proratable water rights (see Section 3.1.2). Historical estimates of TWSA from 1977 to 2000 are provided in Table 3-3.

TABLE 3-2

Target Flows at Sunnyside and Prosser Diversion Dams

Water Supply Estimate[1] for Period (million AF)				Target Flow (cfs) from date of estimate through October downstream of Sunnyside and Prosser Diversion Dams	
April through September	**May through September**	**June through September**	**July through September**	**Without Basin Conservation Program**	**With Basin Conservation Program**
3.2	2.9	2.4	1.9	600	900
2.9	2.65	2.2	1.7	500	800
2.65	2.4	2	1.5	400	700
<2.65	<2.4	<2.0	<1.5	300	300[2]

Notes:

(1) "Estimate" refers to the Project Superintendent's water supply estimate.

(2) Only increased with reduced diversions below Sunnyside.

Source: EES, et al. (2003)

Historically, (except Water Year (WY) 1993) the prorationing period has not started until the date of storage control. This means that water has been available for all entitlements until May. The amount of proration is determined monthly, biweekly, or as needed by project operations and this information is provided to water using entities at manager meetings. The nonproratable users can divert their full irrigation entitlements. This amount is deducted from the water supply available for irrigation entitlements with the remainder available for the proratable irrigation entitlements. The recognized quantities of nonproratable and proratable irrigation entitlements are summarized in Table 3-4. Proratable water users did not receive all of their proratable entitlement in 1992, 1993, 1994, 2001, and 2005 (Reclamation, 2002). One of the goals of increased storage in the Yakima River Basin is to provide a more reliable water source for the proratable water rights by increasing the total water supply available.

TABLE 3-3

Historical TWSA Estimates by Month in KAF, Commencing WY 1977 & YRBWEP Title XII Target flows in cfs, Commencing WY 1995

Month	Mar's Apr		XII	Apr		XII	May		XII	Jun		XII		Jul		XII		Aug		Sep	
YEAR	**KAF**	**Notes**	**cfs**	**KAF**	**Notes**	**cfs**	**KAF**	**Notes**	**cfs**	**KAF**	**Notes**	**cfs**	**Notes**	**KAF**	**Notes**	**cfs**	**Notes**	**KAF**	**Notes**	**KAF**	**Notes**
1977	-		-	2,037		-	-		-	-		-		-		-		-		-	
1978	3,088		-	2,678		-	2,341		-	-		-		1,433		-		920		-	
1979	2,770		-	2,657		-	2,460		-	1,964		-		-		-		-		-	
1980	3,268		-	3,147		-	2,705		-	2,121		-		-		-		-		-	
1981	2,690		-	2,367		-	2,296		-	1,979		-		-		-		-		-	
1982	3,433		-	3,256		-	3,005		-	-		-		-		-		-		-	
1983	3,453		-	3,392		-	2,941		-	2,271		-		-		-		-		-	
1984	2,956		-	2,786		-	2,501		-	2,200		-		-		-		-		-	
1985	3,106		-	3,111		-	2,868		-	2,395		-		1,529		-		899		-	
1986	3,061		-	2,668		-	2,284		-	1,800		-		1,367		-		-		-	
1987	2,558		-	2,559		-	2,297		-	1,661		-		1,301		-		-		-	
1988	2,377		-	2,253		-	2,065		-	1,710		-		1,349		-		-		-	
1989	2,946		-	3,071		-	2,666		-	2,192		-		-		-		-		-	
1990	3,446		-	3,268		-	2,824		-	2,417		-		1,717		-		-		-	
1991	2,938		-	2,962		-	2,742		-	2,261		-		1,854		-		-		-	
1992	2,853		-	2,422		-	2,268		-	1,497	4	-		1,155	1	-		788	1	324	1
1993	2,062		-	1,974	5	-	1,842	2	-	1,405	1,2	-		1,126	1,2	-		774	1,2	415	1,2
1994	2,169	2	-	2,016	2	-	1,691	2	-	1,191	1,2	-		934	1,2	-		593	1,2	283	1,2
1995	3,284	2	600	3,044	2	500	2,666	2	500	2,088	2	400		1,572	2	400		-		-	
1996	3,268	2	600	2,872	2	400	2,530	2	400	2,003	2	400		1,463	2	400		-		-	
1997	4,055	2	600	4,542	2	600	3,836	2	600	2,670	2	600		1,935	2	600		-		-	
1998	3,193	2	500	2,982	2	500	2,548	2	400	2,017	1,2	400		1,536	1,2	400		-		-	
1999	4,179	2	600	4,198	2	600	3,649	2	600	3,017	2	600		1,913	1,2	600		-		-	
2000	3,319	2	604	3,305	2	604	2,691	2	5,046	2,175	2	404	3	1,615	2	404	3	-		-	
Average	*3,064*		*-500*	*2,899*		*-500*	*2,596*		*-400*	*2,049*		*-400*		*1,487*		*-300*		*795*		*341*	

Notes:
XII = YRBWEP Title XII Target Flows – April (or current month) through October. KAF = thousand acre-feet
1. Based upon adopted forecast.
2. Does not include October's entitlements, runoff, or return flows.
3. Includes YRBWEP lease and acquisition water.
Source: Reclamation (2002)

3.2.3 Municipal Demand Centers

There are fifteen municipalities within the Yakima River Basin. Seven of the municipalities use water above Parker gauge, and the other eight use water from below the Parker gauge (Figure 3-4). Figure 3-4 shows the location of each municipal diversion and return flow in relation to the Yakima River, its tributaries, and gauge locations. Figure 3-5 is a simplified version of Figure 3-4 that does not include the tributaries. The population of the Yakima River Basin was approximately 288,000 people in the year 2000. Based on projections developed for the 2003 Yakima Basin Watershed Plan, the basin's population is projected to increase to over 418,000 people by the year 2020, and 531,000 people by the year 2050 (EES, et al., 2003). Population growth will increase municipal water demand within the basin.

Water users obtain their water from municipal systems, small public water systems, individual household wells, and wells owned by self-supplied industrial users. Table 3-5 presents current (year 2000) and projected demands through year 2020 for municipal water systems (EES, et al., 2003). Municipal demands have been grouped by USGS streamflow gauge control point. The City of Yakima diverts the largest quantity of surface water for municipal use (greater than 10 cfs), followed by the community of Cle Elum (approximately 1 cfs), and other smaller diversions.

The estimated total additional volume of water needed to meet future municipal demand by the year 2020 for all of the municipalities listed in Table 3-5 is 25,438 AF per year. This volume of water represents demand for additional potable water in the Yakima Basin. Some portion of the additional water needed by each municipality to support growth through 2020 represents the potential demand for municipal ASR, which is discussed further in Section 5 for select municipalities.

Current and future rural residential water demand (not including municipal water demand) was also estimated for four subareas within the Yakima Basin as part of the watershed plan (EES, et al., 2003). Each of the subareas has been associated with the USGS streamflow gauge nearest to the mouth of the subarea. The Upper Yakima Subarea is associated with the Umtanum gauge, the Middle Yakima Subarea and Naches Subarea are associated with the Parker gauge, and the Lower Yakima Subarea is associated with the mouth of the Yakima Basin. The additional volume of water needed to meet future residential demand by the year 2020 for the users listed in Table 3-6 is 19,860 AF per year. This volume of water represents demand for additional non-municipal potable water in the Yakima Basin.

Monthly shaping factors were used to distribute the annual volume of new municipal and residential water on a monthly basis (Tables 3-7 and 3-8). The shaping factors are based on monthly water production by the City of Yakima from 2004 to 2006 (Brown, personal communication, 2007). The monthly factors were assumed to be representative of municipal water use throughout the Yakima Basin; however, water demand from irrigation and permit-exempt wells may vary within the basin.

TABLE 3-4

TWSA Irrigation Entitlements (AF) recognized by 1945 Consent Decree
April 1st through September 30th, and October 1st through 30th

Month	Nonproratable	Accumulated Nonproratable	Proratable	Accumulated Proratable	Monthly Total	Accumulated Remaining Entitlement
April	160,973	1,070,271	93,857	1,239,199	254,830	2,309,470
May	186,637	909,298	228,463	1,145,342	415,100	2,054,640
June	182,240	722,661	258,150	916,879	440,390	1,639,540
July	189,640	540,421	268,236	658,729	457,840	1,199,150
August	186,058	350,817	257,822	390,493	443,880	741,310
September	164,759	164,759	132,671	132,671	297,430	297,430
October	115,115	115,115	44,025	44,025	159,140	159,140

Notes:

1. Accumulated refers to the sum of all the remaining entitlements. For example the accumulated nonproratable amount for the month of April includes the nonproratable amounts for the months of April through September.

Source: Reclamation (2002)

TABLE 3-5

Current and Future Municipal Water Demand in the Yakima Basin

Municipality	Estimated Year 2000 Water Use (AF per year)[1]	Projected 2020 Future Water Use (AF per year)[1]	Additional Water Needed to Support Growth through 2020 (AF per year)
Above Parker Gauge			
Ellensburg	4,820	7,062	2,242
Cle Elum	897	1,121	224
City of Yakima	17,151	19,393	2,242
Nob Hill Water Association	3,811	5,717	1,906
Selah	2,915	3,699	784
Union Gap	1,211	1,586	375
Terrace Heights (Yakima County)	673	1,233	560
Total Above Parker Gauge	*31,478*	*39,811*	*8,333*
Below Parker Gauge			
Sunnyside	3,251	4,260	1,009
Grandview	3,139	5,381	2,242
Toppenish	2,018	2,643	625
Wapato	1,345	3,139	1,794
Benton City	224	1,345	1,121
Prosser	3,139	3,924	785
Richland	9,192	15,358	6,166
West Richland	2,915	6,278	3,363
Total Below Parker Gauge	*25,223*	*42,328*	*17,105*

Notes:
1. Year 2000 water use estimate and projected 2020 water use from the 2003 Watershed Management Plan, Yakima River Basin (EES, et al., 2003). Water use estimates are based on average day demand.

TABLE 3-6

Current and Future Residential Water Demand in the Yakima Basin[1]

Location	Annual Demand (AF) 2000	Annual Demand (AF) 2020	Additional Water Needed to Support Growth through 2020
Upper Yakima Subarea			
Other Community and Class B PWS (16)	3,139	4,551	1,412
Non-Community PWS (19)	988	1,432	444
Yakima Training Center (17)	90	90	0
Households with own well (18)	5,652	8,195	2,543
Upper Yakima Total (Above Umtanum Gauge)	9,869	14,268	4,399
Middle Yakima Subarea			
Other Community and Class B PWS (16)	3,520	4,611	1,091
Non-community PWS (19)	173	226	53
Yakima Training Center (17)	90	90	0
Households with own well (18)	18,887	24,741	5,854
Naches Subarea (No systems with 1,000 connections)			
Community and Class B PWS (16)	1,487	2,022	535
Non-Community PWS (19)	680	925	245
Households with own well (18)	2,598	3,533	935
Naches and Middle Yakima Subtotal (Above Parker Gauge)	27,435	36,148	8,713
Lower Yakima Subarea			
Other Community and Class B PWS (16)	6,837	8,957	2,120
Non-Community PWS (19)	305	399	94
Households with own well (18)	14,627	19,161	4,534
Lower Yakima Subarea Subtotal (Above Mouth of Yakima Basin)	21,769	28,517	6,748
Total	59,073	78,933	19,860

Notes:

1. Year 2000 water use estimate and projected 2020 water use from the 2003 Watershed Management Plan, Yakima River Basin (EES, et al., 2003).

TABLE 3-7

Seasonal Demand of Additional Water Needed to Support Municipal Growth through 2020 in the Yakima Basin

Municipality	Annual (AF per year)[1]	Seasonal Demand of Additional Water Needed to Support Growth through 2020 (AF per month)[2]											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Above Umtanum Gauge													
Ellensburg	2,242	99.6	93.8	110.1	152.3	224.4	273.4	313.6	296.9	241.4	184.7	138.8	112.9
Cle Elum	224	9.9	9.4	11.0	15.2	22.4	27.3	31.3	29.7	24.1	18.5	13.9	11.3
Above Parker Gauge													
City of Yakima	2,242	99.6	93.8	110.1	152.3	224.4	273.4	313.6	296.9	241.4	184.7	138.8	112.9
Nob Hill Water Association	1,906	84.7	79.7	93.6	129.5	190.8	232.4	266.6	252.4	205.2	157.0	118.0	96.0
Selah	784	34.8	32.8	38.5	53.3	78.5	95.6	109.6	103.8	84.4	64.6	48.5	39.5
Union Gap	375	16.7	15.7	18.4	25.5	37.5	45.7	52.4	49.7	40.4	30.9	23.2	18.9
Terrace Heights (Yakima County)	560	24.9	23.4	27.5	38.0	56.1	68.3	78.3	74.2	60.3	46.1	34.7	28.2
Above Prosser Gauge													
Sunnyside	1,009	44.8	42.2	49.6	68.5	101.0	123.0	141.1	133.6	108.7	83.1	62.5	50.8
Grandview	2,242	99.6	93.8	110.1	152.3	224.4	273.4	313.6	296.9	241.4	184.7	138.8	112.9
Toppenish	625	27.8	26.2	30.7	42.5	62.6	76.2	87.4	82.8	67.3	51.5	38.7	31.5
Wapato	1,794	79.7	75.1	88.1	121.9	179.6	218.7	250.9	237.6	193.2	147.8	111.1	90.4
Above Kiona Gauge													
Benton City	1,121	49.8	46.9	55.1	76.2	112.2	136.7	156.8	148.5	120.7	92.3	69.4	56.5
Prosser	785	34.9	32.8	38.6	53.3	78.6	95.7	109.8	104.0	84.5	64.7	48.6	39.5
Above Mouth of Yakima Basin													
Richland	6,166	273.9	258.0	302.9	418.9	617.3	751.8	862.4	816.6	664.0	508.0	381.8	310.6
West Richland	3,363	149.4	140.7	165.2	228.5	336.7	410.1	470.3	445.4	362.1	277.0	208.2	169.4
TOTAL	**25,438**	**1,130**	**1,064**	**1,250**	**1,728**	**2,547**	**3,102**	**3,558**	**3,369**	**2,739**	**2,096**	**1,575**	**1,281**

Notes:

1. Annual municipal water demand from Table 3-5. Represents additional water needed to support growth through 2020.

2. Seasonal municipal water demand approximated using domestic water use shaping factors from City of Yakima monthly average water production (2004-2006).

TABLE 3-8
Seasonal Demand of Additional Water Needed to Support Residential Growth through 2020 in the Yakima Basin

Location	Annual (AF per year)[1]	Seasonal Demand of Additional Water Needed to Support Growth through 2020 (AF per month)[2]											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Yakima Subarea													
Other Community and Class B PWS (16)	1,412	62.7	59.1	69.4	95.9	141.4	172.2	197.5	187.0	152.1	116.3	87.4	71.1
Non-Community PWS (19)	444	19.7	18.6	21.8	30.2	44.4	54.1	62.1	58.8	47.8	36.6	27.5	22.4
Yakima Training Center (17)	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Households with own well (18)	2,543	113.0	106.4	124.9	172.8	254.6	310.1	355.7	336.8	273.8	209.5	157.5	128.1
Upper Yakima Total (Above Umtanum Gauge)	4,399	195.4	184.1	216.1	298.8	440.4	536.4	615.2	582.6	473.7	362.4	272.4	221.6
Middle Yakima Subarea													
Other Community and Class B PWS (16)	1,091	48.5	45.6	53.6	74.1	109.2	133.0	152.6	144.5	117.5	89.9	67.6	55.0
Non-community PWS (19)	53	2.4	2.2	2.6	3.6	5.3	6.5	7.4	7.0	5.7	4.4	3.3	2.7
Yakima Training Center (17)	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Households with own well (18)	5,854	260.0	244.9	287.6	397.7	586.0	713.8	818.7	775.3	630.4	482.3	362.5	294.9
Naches Subarea (No systems with 1,000 connections)													
Community and Class B PWS (16)	535	23.8	22.4	26.3	36.3	53.6	65.2	74.8	70.9	57.6	44.1	33.1	26.9
Non-Community PWS (19)	245	10.9	10.3	12.0	16.6	24.5	29.9	34.3	32.4	26.4	20.2	15.2	12.3
Households with own well (18)	935	41.5	39.1	45.9	63.5	93.6	114.0	130.8	123.8	100.7	77.0	57.9	47.1
Naches and Middle Yakima Subtotal (Above Parker Gauge)	8,713	387.0	364.6	428.0	591.9	872.3	1062.4	1218.6	1153.9	938.3	717.8	539.5	438.9
Lower Yakima Subarea													
Other Community and Class B PWS (16)	2,120	94.2	88.7	104.1	144.0	212.2	258.5	296.5	280.8	228.3	174.6	131.3	106.8
Non-Community PWS (19)	94	4.2	3.9	4.6	6.4	9.4	11.5	13.1	12.4	10.1	7.7	5.8	4.7
Households with own well (18)	4,534	201.4	189.7	222.7	308.0	453.9	552.8	634.1	600.4	488.2	373.5	280.7	228.4
Lower Yakima Subarea Subtotal (Above mouth of Yakima Basin)	6,748	299.7	282.3	331.5	458.4	675.5	822.8	943.8	893.7	726.7	555.9	417.8	339.9

Notes:

1. Annual water demand from Table 3-6. Represents additional water needed to support growth through 2020.
2. Seasonal municipal water demand approximated using domestic water use shaping factors from City of Yakima monthly average water production (2004-2006).

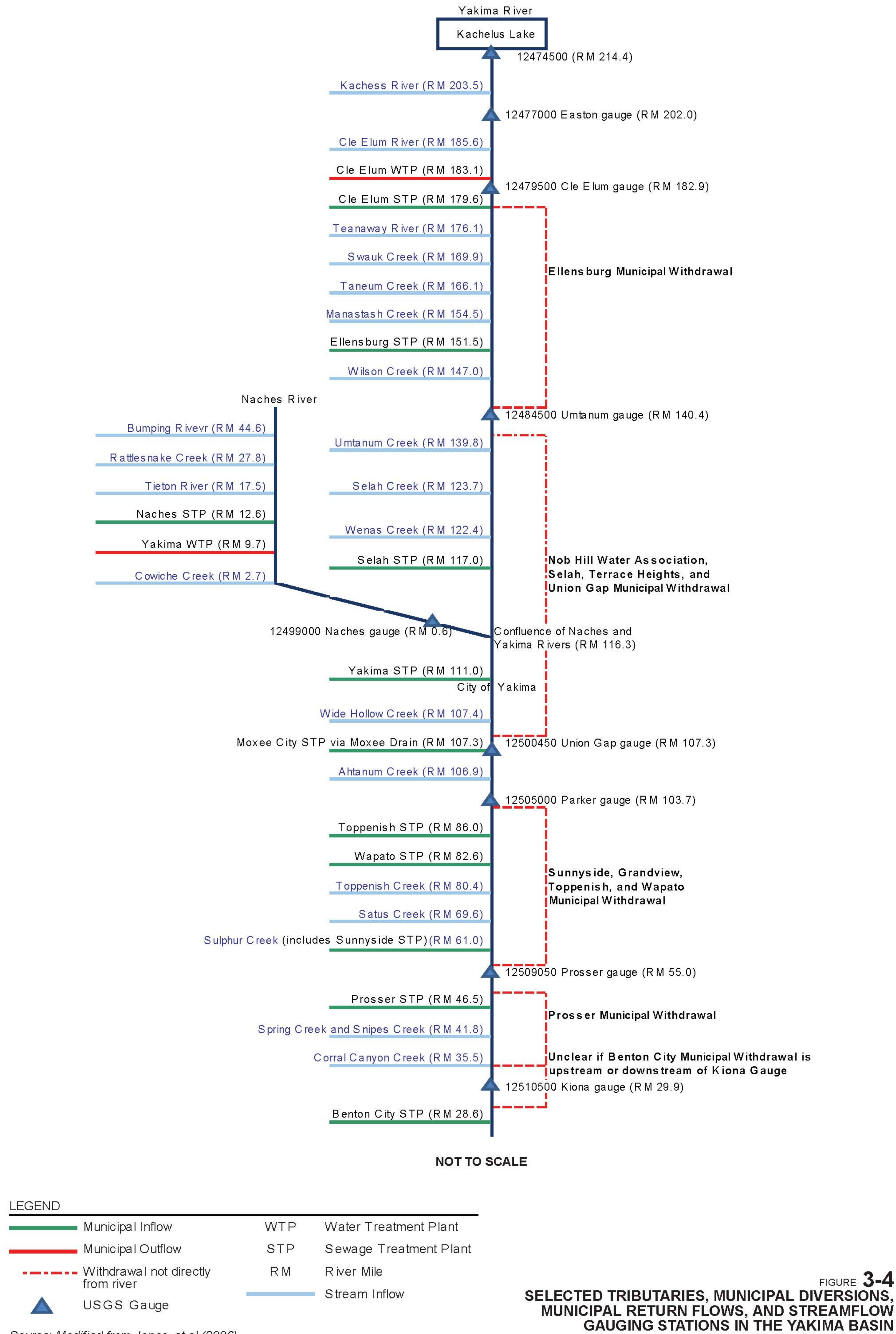

FIGURE **3-4**

SELECTED TRIBUTARIES, MUNICIPAL DIVERSIONS, MUNICIPAL RETURN FLOWS, AND STREAMFLOW GAUGING STATIONS IN THE YAKIMA BASIN

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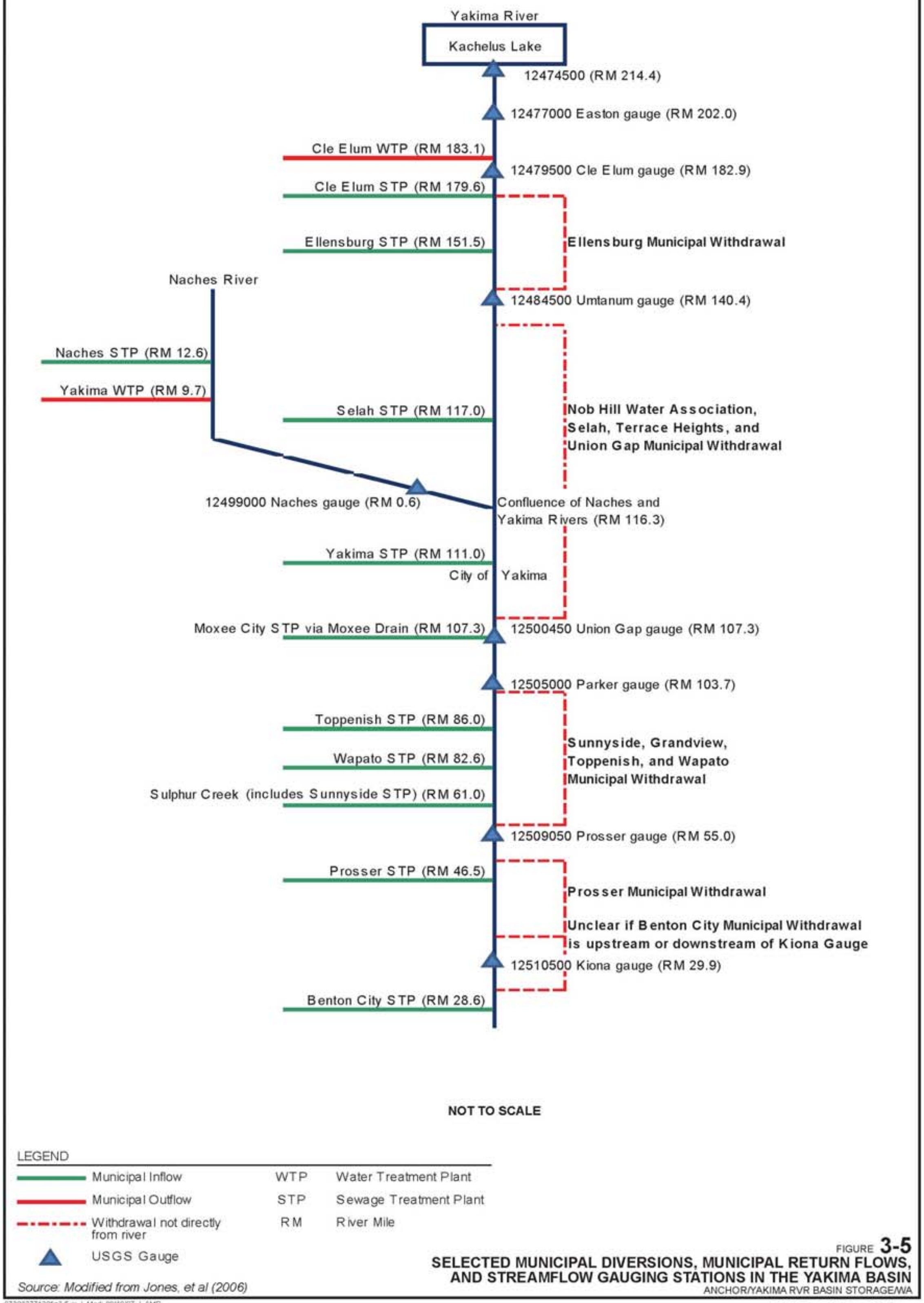

FIGURE 3-5
SELECTED MUNICIPAL DIVERSIONS, MUNICIPAL RETURN FLOWS, AND STREAMFLOW GAUGING STATIONS IN THE YAKIMA BASIN

3.3 HYDROGEOLOGY

This section describes the hydrogeologic units, aquifer properties, ground water levels, and recharge to ground water. These characteristics provide the basis for the ground water storage feasibility assessment.

3.3.1 Hydrogeologic Units

A hydrogeologic unit can be characterized as either an aquifer or an aquitard (also referred to as a confining unit). An aquifer comprises saturated, permeable geologic units that are capable of transmitting useable quantities of water. Aquifers are classified as unconfined and confined. An aquitard is a unit that restricts the movement of ground water.

Studies to quantify ground water resources of the Yakima region normally define two to three aquifers based on lithological differences. Biggane (1982) considers two regional hydrogeologic units: a sedimentary aquifer and a basalt aquifer. Cearlock, et al. (1975) and Foxworthy (1962) refer to 1) a surficial gravel aquifer; 2) the Ellensburg Aquifer; and 3) the basalt aquifer. Both the sedimentary and basalt aquifers comprise a number of water-bearing and aquitard strata that possess different hydraulic properties.

In this study, a three aquifer classification is used (from surface down, youngest to oldest): Quaternary unconsolidated sediments/alluvium, the Ellensburg Formation, and Miocene basalts. These three classifications are discussed below.

- Quaternary unconsolidated sediments/alluvium range in thickness from a few feet to several tens of feet. The sediment consists of recent fluvial deposits from river and creek systems in the area, as well as scattered loess deposits associated with these fluvial systems. The other unconsolidated deposits also contain alluvial deposits, as well as fluvial, alluvial fan, colluvial, and other wind-blown deposits. Most wells in these units are for residential use.

- The Upper Ellensburg Formation has its greatest thickness at the center of the synclinal basins and thins against the slopes of the anticlinal basalt ridges. The sedimentary aquifer ranges in thickness from about 300 feet to 2,000 feet and can be divided into three units: upper, middle, and lower. The upper member of the Upper Ellensburg Formation attains depths of 900 feet and contains wells used for domestic, irrigation, and commercial/industrial purposes. The middle Ellensburg confining unit comprises interbedded clays, silts, and fine sands between 100 to 400 feet thick. Some wells have screened intervals that span more permeable zones within this layer. The lower Ellensburg confining unit comprises a number of semiconnected water producing zones with different confining pressures. The principal water producing zones occur in weakly cemented permeable layers of gravel and well-sorted sand. Although yields can be high if extensive coarse-grained layers are penetrated, the confined zone is generally not as permeable as the unconfined aquifer and tends to have lower yields. A limited number of wells are completed in this layer.

- The basalt aquifer underlies the sedimentary aquifer and also comprises a number of water-bearing and aquitard zones. Aquifer zones occur within joints, fractured and brecciated units of the Columbia River Basalt Group (CRBG), as well as in interbedded sedimentary layers (e.g., the Selah member of the Lower Ellensburg Formation). Aquitard zones comprise competent basalt between the flow tops and bottoms and major joints.

The USGS mapped the extent of the basalt aquifers and interbed formations using well log data, contour maps, and geologic maps (Jones and Vaccaro, 2008). The basalt aquifers and interbed formations (from shallowest to deepest) include the Saddle Mountains basalt aquifer, the Mabton interbed formation, the Wanapum basalt aquifer, the Vantage interbed unit, and the Grande Ronde basalt aquifer. The Saddle Mountains formation has a maximum and average thickness of 1,110 feet and 500 feet, respectively. The Mabton formation has a maximum and average thickness of 250 feet and 70 feet, respectively. The Wanapum formation has a maximum and average thickness of 1,180 feet and 600 feet, respectively. The Vantage formation has a maximum and average thickness of 135 feet and 30 feet, respectively. The thickness of the Grande Ronde formation was not determined in the USGS study (Jones and Vaccaro, 2008).

3.3.2 Ground Water Levels

The National Water Information System (NWIS) contains the well log database developed for the Yakima River Basin Project by the USGS. Over 1,900 wells were identified in the project area. The wells were then categorized according to total depth and depth to water. Wells were broken into categories based on water depth and total well depth. Figure 3-6 shows the location of selected wells that are less than 200 feet deep and the maximum depth to water measured from 2000 to 2001, where available. Hydrographs of water levels in unconsolidated and consolidated sedimentary deposits for selected wells are provided in Appendix A. Hydrographs of the water levels in wells completed in the confined basalt group are also provided in Appendix A.

3.3.3 Aquifer properties

Ground water exists and is analyzed relative to its dynamic state (i.e., its ability to move through the subsurface) and its static state (i.e., the volume of water that exists at a given point in time). Ground water moves through an aquifer in relation to hydraulic boundaries, such as rivers or lakes, and moves from higher elevation to lower elevation. The transmissivity of an aquifer is measured because it describes how easily water moves through the aquifer: its dynamic component. Transmissivity is the best indicator of well production and is therefore frequently reported in water supply studies. Many methods for determining transmissivity have been developed over the years and they account for a variety of hydrogeologic settings. The storage coefficient of an aquifer describes the static component of the aquifer: the volume of water within the pore spaces of the aquifer formation. Storage coefficients are more difficult to measure in an aquifer. Aquifer transmissivity and storage coefficient together are used to describe the time-varying dynamics of an aquifer system and how it responds to recharge, pumping, or other stresses.

When a well is initially pumped, water is withdrawn from the pore spaces in the aquifer. The behavior of an aquifer during injection or controlled recharge is analogous (but inverse) to pumping. During the early stages of pumping, the static storage volume in the aquifer is providing a relatively large proportion of the water to the well. As pumping continues over time, the influence of the well extends outward from the well to hydraulic boundaries of the aquifer system, eventually establishing an equilibrium within the dynamics of the aquifer as a whole (i.e., the recharge and discharge continuum). Therefore, during the later stages of pumping, the dynamic flowing volume in the aquifer provides a relatively large proportion of the water to the well. Accordingly, a long-term continuous ground water withdrawal generally causes a permanent change to the recharge-discharge equilibrium of an aquifer, which is often reflected as a decrease in stream base flow.

Estimates of the storativity and specific yield within the Yakima River Basin were obtained for confined and unconfined aquifers. Storativity values are based on a literature review of storativity values for basalt aquifers. Values for the Wanapum basalts (Deobald, et al., 1995) and a generalized confined aquifer (Barnett, 2000) provide a reasonable range for storativity that is between 0.00002 and 0.0005.

A reasonable range of the specific yield of alluvium and unconsolidated sediments that comprise the unconfined aquifers, based on the range of glaciofluvial material, is 0.03 to 0.2 (Whiteman, et al., 1994). The materials in the shallow Yakima River Basin are comprised of coarser materials which would have a higher specific yield. Silts and fine sands tend to occur deeper in the sedimentary sequence and correspond more to lacustrine deposits, which have a lower specific yield.

The hydraulic conductivity of the alluvium and unconsolidated sediments ranges from 5.1 to 26 feet per day based on the median and 75^{th} percentile of the hydraulic conductivity estimates of overburden in the Columbia Basin (Hansen, et al., 1994). The median and 75^{th} percentile are representative of the coarse-grained character along many sections of the streams in the basin.

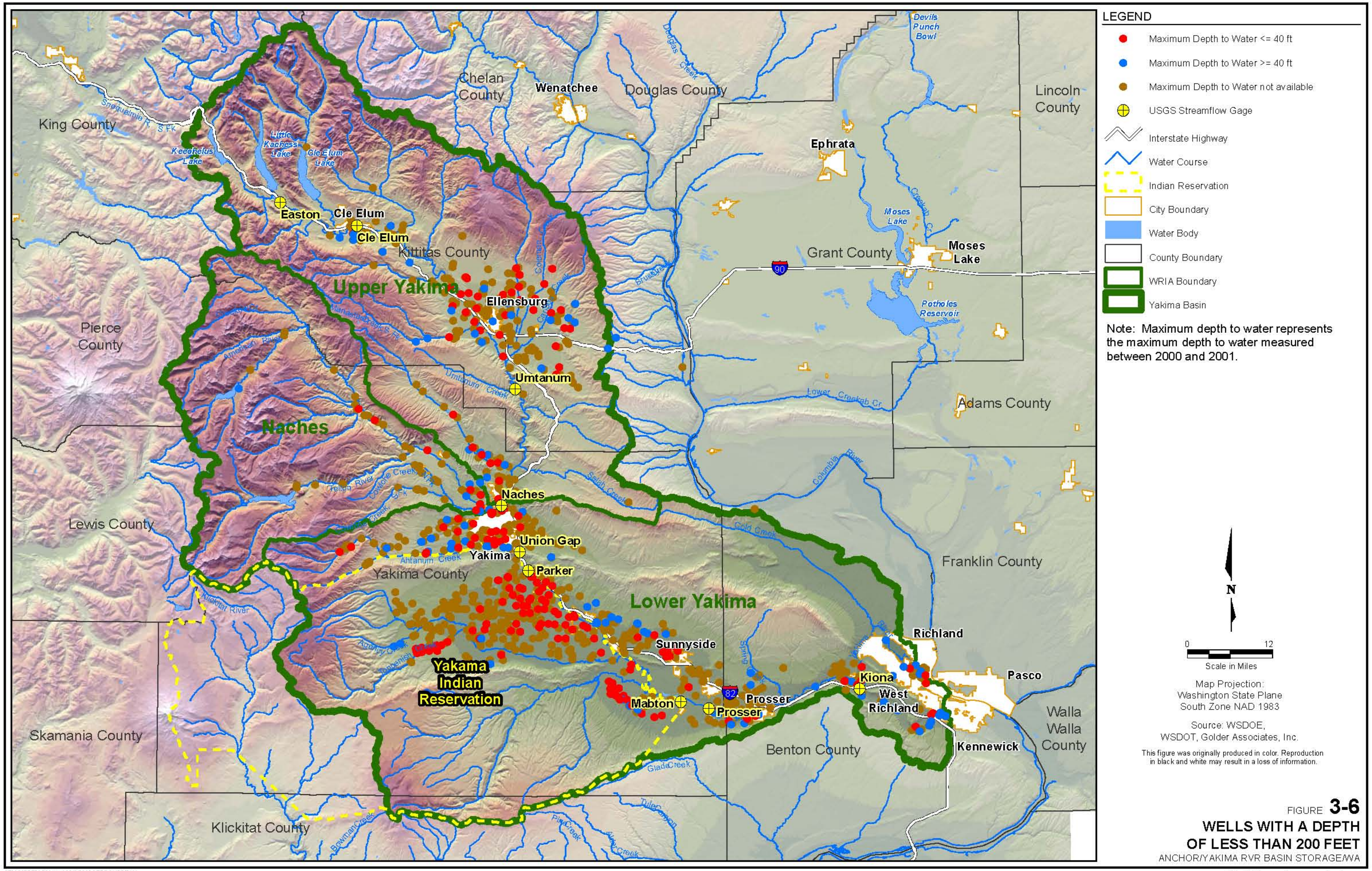

FIGURE 3-6
WELLS WITH A DEPTH OF LESS THAN 200 FEET

3.3.4 Recharge

A USGS study of ground water recharge under pre- and post-development conditions in the Yakima River Basin provided the following summary of the ground water recharge in the Yakima River Basin (Vaccaro and Olsen, 2007). The USGS used two models to estimate ground water recharge to the Yakima River Basin aquifer system for pre-development conditions (estimate of natural conditions) and current conditions (a multiyear, 1995 to 2004, composite). Daily values of recharge were estimated for water years 1950 to 1998 using Precipitation-Runoff Modeling System (PRMS) watershed models for four mainly forested upland areas. Water years 1950 to 2003 were evaluated using the Deep Percolation Model applied to 17 semiarid to arid areas in the basin (Vaccaro and Olsen, 2007). Figure 3-7 shows the annual recharge for water year 2001 in the Yakima River Basin.

The mean annual recharge under pre-development conditions was estimated to be about 11.9 inches or 5,450 cfs (about 3.9 million AF) for the 6,207 mi^2 in the modeled area. Within the modeled area, recharge ranged from 0.08 inch (1.2 cfs) to 34 inches (2,825 cfs). About 90 percent of the total recharge occurred in the upper Yakima and Naches modeled areas (Vaccaro and Olsen, 2007).

The mean annual recharge to the aquifer system under current conditions was estimated to be about 15.6 inches, or 7,149 cfs (about 5.2 million AF). The increase in recharge is due to the application of irrigation water to croplands. The annual quantity of irrigation was more than five times the annual precipitation for some of the modeled areas. Mean annual actual evapotranspiration was estimated to have increased from pre-development conditions by more than 1,700 cfs (about 1.2 million AF) due to irrigation (Vaccaro and Olsen, 2007).

Ground water in the basalt is recharged directly by infiltration along the anticlinal ridges and along losing reaches of rivers where the basalt is exposed at the surface. The basalt aquifer is also recharged by downward flow from the sedimentary aquifer in portions of the basin, principally along the edge of basins. Ground water in the alluvium is recharged by infiltration of precipitation, seepage from streams, irrigation canals and irrigated land and upward leakage from confined aquifers.

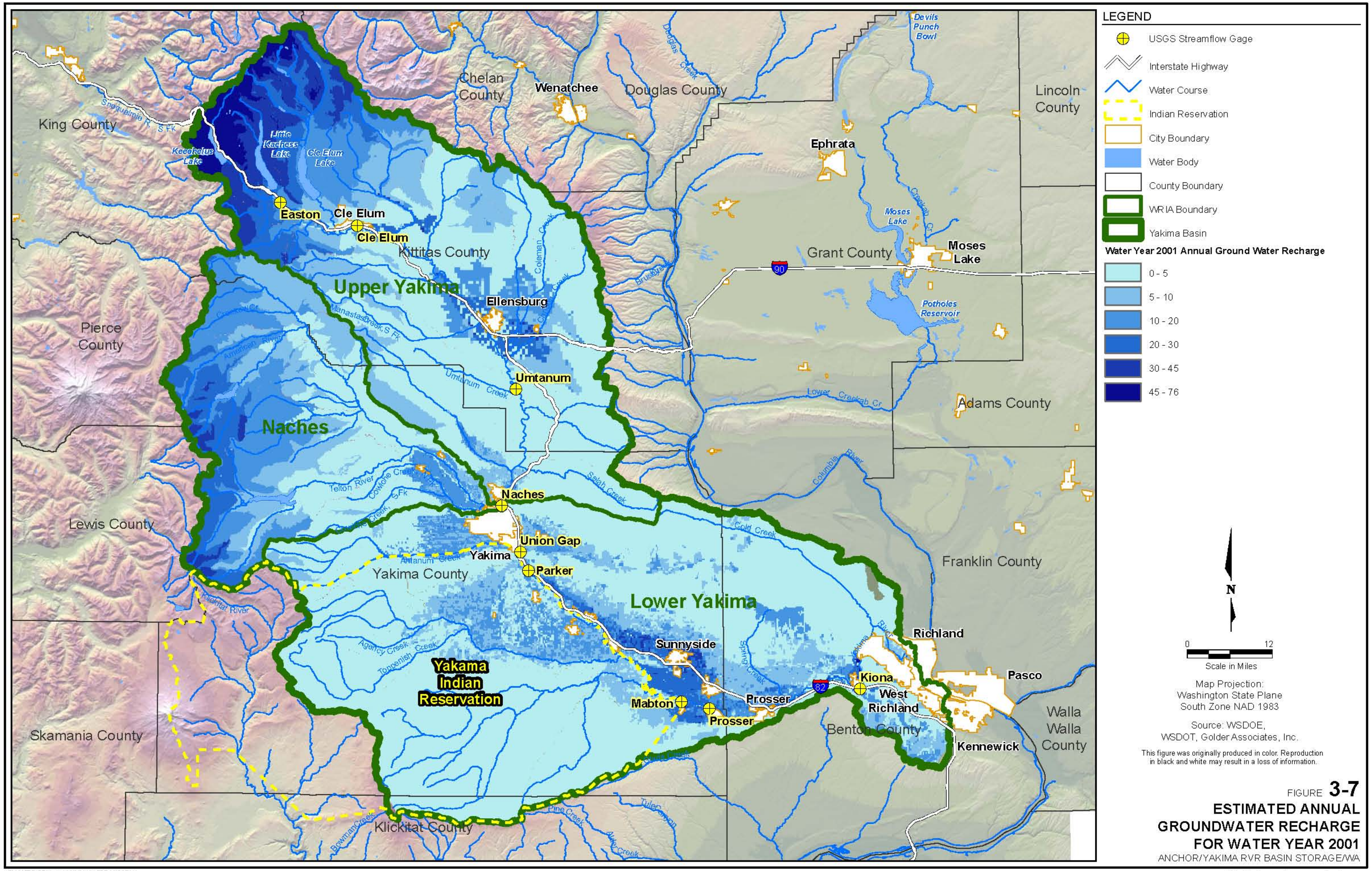

FIGURE 3-7
ESTIMATED ANNUAL GROUNDWATER RECHARGE FOR WATER YEAR 2001

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4.0 SURFACE RECHARGE WITH PASSIVE RECOVERY

The surface recharge analysis considered the characteristics and volumes of water needed or available for infiltration and subsequent return flow, focusing on the ability to increase stream flows during July, August, and September. The analysis identified a range of total acres of land needed based on a range of assumptions about the geology and aquifer properties. Specific sites were not identified for surface recharge locations because of the lack of site-specific hydrogeologic data. Instead a map of the possible locations for sites was developed that could be used with more site-specific data.

4.1 METHODOLOGY

The approach for evaluating surface recharge includes several components outlined below and shown on Table 4-1 and Figure 4-1. An infiltration pond would receive water from the irrigation canal system and infiltrate to ground water. The ground water would discharge to an adjacent stream and an "accretion" of flow would occur. The ground water storage capacity for surface recharge is reflected in the combined capability of the pond to store and infiltrate water and the ability of the aquifer to transmit and discharge the water back to the river. The volume analyses described in Sections 4.2 through 4.5 are based on a monthly time step. Details at a smaller time step (e.g., days or weeks) are not evaluated.

The four components to the methodology are as follows:

1. Infiltration Capacity (Section 4.2). This describes a range of pond capacities that could be expected in the Yakima River Basin. The analysis is based on standard analytical equations and suggested approaches in the Washington Department of Transportation (WSDOT) Design Manual for infiltration facilities (WSDOT, 2006).

2. Return Flow Processes (Section 4.3). This describes the volume and timing of the infiltration that reaches the ground water table and moves from beneath the infiltration pond to a discharge zone (i.e., a stream or river). The analysis is based on an analytical model (SDF View), developed by Colorado State University (2005).

3. Potential Site Locations (Section 4.4). The aquifer properties, surficial geology, land cover, range of infiltration areas, and return flow processes are considered to evaluate the potential for infiltration in specific areas of the Yakima Valley. However, specific sites are not identified.

4. Surface Recharge Return Flow Volumes (Section 4.5). This section combines the various components into a month-by-month estimate of return flow volumes from surface recharge using two approaches to determine delivery volumes to the infiltration ponds.

4.2 INFILTRATION CAPACITY AND VOLUMES

The ability to infiltrate water from a pond is determined by a number of factors, including the area and geometry of the pond, infiltration capacity of the soil, depth to ground water, and ponding depth. Two approaches were used to estimate infiltration capacity. The results of these estimates suggest that an average infiltration capacity of 20 to 60 AF per acre per month would be reasonable to expect for the study area. Based on these infiltration capacities, an area of 166 to 500 acres of land would be required to infiltrate 10,000 AF of water in one month.

Details of the infiltration estimates are as follows:

- A representative 20-acre infiltration pond with a ponding depth of 2 to 5 feet was assumed, and a series of infiltration estimation equations were used to estimate the infiltration capacity (WSDOT Design Hydraulics Manual, 2006, Chapter 4-5 Infiltration Design Guidance). Key parameters used in the equations are summarized on Table 4-2. Based on these calculations, infiltration capacities of 30 to greater than 100 AF/acre per month are estimated.
- A corollary analysis was made using actual performance data for five large infiltration facilities in Arizona. Since 1997, the Central Arizona Project (CAP) has designed and constructed five large infiltration facilities to infiltrate surface water for ground water recharge. Currently, these five facilities encompass approximately 400 acres and have the capacity to infiltrate 12,650 AF of water per month. Table 4-3 summarizes some of the design information for these facilities, and Appendix C contains more detailed information on each facility. The operational results at these facilities indicate an infiltration capacity of greater than 50 AF/acre per month. Some facilities have achieved much higher specific infiltration rates (e.g., greater than 100 AF/acre/month).

The time that it takes for infiltration to move from the ground surface to the water table is expected to vary from days to weeks. An estimate of one month is assumed. The infiltration profile used to evaluate return flow volume and timing is discussed in Section 4.5.

<u>**TABLE 4-1**</u>

Timing of Delivery, Infiltration, and Beginning of Return Flows (Accretion) to River

Month		Jan 31	Feb 31	Mar 28	Apr 30	May 31	Jun 30	Jul 31	Aug 31	Sep 30	Oct 31	Nov 30	Dec 31
May	Delivery to Infiltration Pond					X							
	Infiltration Pond to Aquifer												
	Aquifer Discharge to Stream												
Jun.	Delivery to Infiltration Pond						X						
	Infiltration Pond to Aquifer												
	Aquifer Discharge to Stream												
Jul.	Delivery to Infiltration Pond							X					
	Infiltration Pond to Aquifer												
	Aquifer Discharge to Stream												
Aug.	Delivery to Infiltration Pond								X				
	Infiltration Pond to Aquifer												
	Aquifer to Stream												
Sept.	Delivery to Infiltration Pond									X			
	Infiltration Pond to Aquifer												
	Aquifer Discharge to Stream												
Oct.	Delivery to Infiltration Pond										X		
	Infiltration Pond to Aquifer												
	Aquifer Discharge to Stream												

Notes:

Indicates time over which infiltration from pond to aquifer is occurring.

Indicates time over which the accretion to the river is occurring. Accretion to the river also extends into the following year.

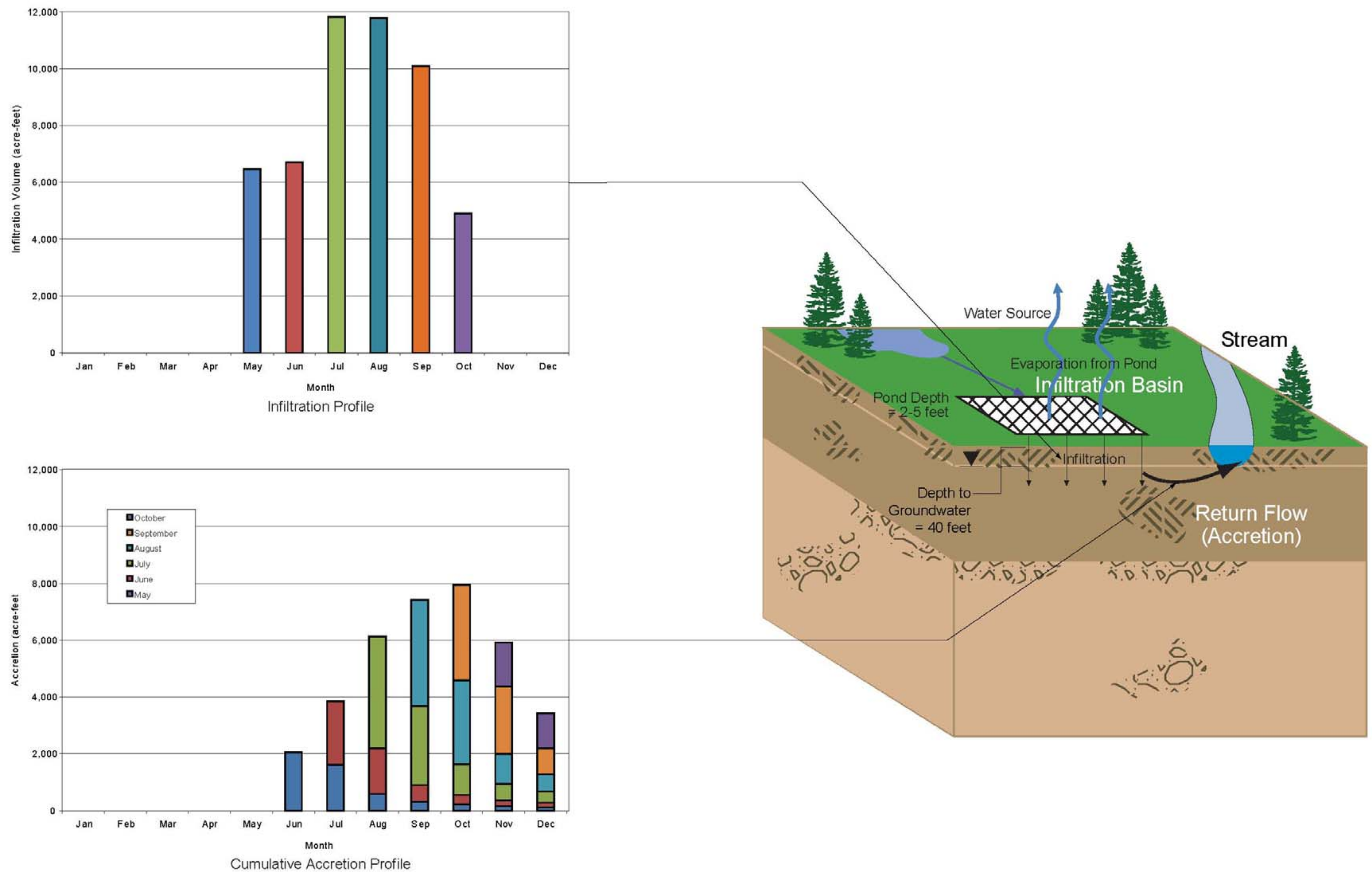

FIGURE **4-1**
SURFACE RECHARGE SCHEMATIC
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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Golder Associates

4.3 RETURN FLOW ANALYSIS

The relationship between the pumping of a well and the resulting depletion of a nearby stream has been derived by several investigators (Theis, 1941; Conover, 1954; Glover and Balmer, 1954; Glover, 1960; Theis and Conover, 1963; Hantush, 1964, 1965). The effects of recharge are identical to the effects of pumping except the direction of flow is reversed (Jenkins, 1968). The return flow to the stream from surface recharge is defined as the "accretion" to the river, as opposed to depletion from the river. The terms stream depletion, or stream depletion factor (SDF), are used in the literature, and for the analysis in this report the term SDF is used in the context of return flow or accretion to the river.

A program called SDF View, version 2.0.11 (Colorado State University, 2005) was used to solve the analytical equations that determine the rate and volume of return flow from a given rate and volume of infiltration. The SDF approach assumes that the infiltration has reached the water table and uses a SDF factor that is a function of the distance between a site and a stream, the transmissivity of the aquifer, and the specific yield of the aquifer. A SDF value and time series of infiltration volumes are input into the SDF program to generate a stream accretion function, which estimates the timing and volume of accretion to a river from the recharge to an aquifer. The equation used to calculate the SDF value is:

$$SDF = \frac{x^2 S}{T} \text{, where}$$

x = effective distance from the infiltration basin to the surface water source (ft)
S = specific yield (dimensionless)
T = transmissivity (ft^2/day)

The SDF value has units of days. The SDF View analysis is based on the following assumptions:

- The aquifer is unconfined, isotropic, homogeneous, and semi-infinite with a constant transmissivity.
- The stream is of constant temperature, and can be represented by a linear boundary that fully penetrates the aquifer.
- Water is added instantaneously to storage, and the infiltration rate is uniform over the time-step of the analysis.
- There are no other losses or gains to streamflow from pumping or return flows. For this study, the analysis therefore represents the additional accretion to a stream that would result from surface infiltration.

TABLE 4-2

Key Parameters Used in the Infiltration Pond Equations

Infiltration Ponds

Length of Pond Bottom (ft)	1,500
Width of Pond Bottom (ft)	600
Area of Bottom of Pond (acres)	20
Pond Side Slopes (3:1 typical)	3

Depth of Pond, Dpond	Depth to Water Table, Dwt	Hydraulic Conductivity, Kequiv[1]	Area of Pond Bottom, Apond	Hydraulic Gradient, i[2]	CFsize[3]	Size Adjusted Infiltration Rate, f[4]	CFaspect[5]	CFsilt/bio[6]	Performance Adjusted Infiltration Rate, fcorr	Infiltration Capacity		
ft	ft	ft/day	acres			ft/day			ft/day	AF/day	AF/mo	AF/Acre/Mo
3	100	10	20	0.35	0.07	3.50	1.03	0.8	2.88	60	1,812	91
3	50	10	20	0.25	0.07	2.50	1.03	0.8	2.06	43	1,294	65
3	30	10	20	0.15	0.07	1.50	1.03	0.8	1.24	26	777	39
3	100	5	20	0.35	0.07	1.75	1.03	0.8	1.44	30	906	45
3	50	5	20	0.25	0.07	1.25	1.03	0.8	1.03	22	647	32
3	30	5	20	0.15	0.07	0.75	1.03	0.8	0.62	13	388	19

Notes:

1. Hydraulic conductivity is consistent with Reclamation’s ground water modeling, which used an average K of 5.8E-4 ft/sec for sediments in the Black Rock area.
2. Hydraulic gradient is conservatively estimated to be less than 1.0 and increases slightly with D_{wt} (Massmann, 2003). Actual gradients could be higher which would result in higher infiltration.
3. CFsize is a correction factor based on Eq. 4-15 in WSDOT Manual. Cfsize approaches 1.0 for small ponds and decreases for larger ponds.
4. Size Adjusted Infiltration Rate, f, is based on Darcy's Law (f = K*i).
5. Cfaspect is a correction factor based on Eq.4-17 in WSDOT Manual and corrects for the ratio of length to width for the pond.
6. CFsilt/bio is a correction factor to account for siltation and biofouling (Table 4-11 in WSDOT Manual). A value of 0.9 indicates a low potential for biofouling and an average to high degree of maintenance and performance monitoring.

TABLE 4-3

Design Information for Infiltration Facilities Associated with the Central Arizona Project

Facility	Basin Dimensions	Infiltration Rates	Infiltration Volumes	Infiltration Capacity	Evaporation Loss	Cost
	Total Acres	Ft/Day	Peak (AF/Month)	AF per Acre per Month	%	
Agui Fria[1]	100	1.2 - 3.5	5,000	50	0.5 - 1.0	$10.5 M
Avra Valley[2]	10.8	2.1 - 3.5	850	79	<1	$0.8M
Hieroglyph Mountains[3]	38	3.0 - 6.0	2,800	73	<1	$5.5M
Santa Cruz[4]	30	N/A	3,977	132	<1	$3.9 M
Pima Mine Road[5]	14	0.7 - 4.2	2,000	142	<1	$11M
Superstition Mountains[6]	N/A	4.0 - 7.0	N/A		N/A	N/A
Tonapah[7]	206	N/A	N/A	N/A	N/A	N/A

Notes
1. Completed in 2003. Seven basins each about 6 feet deep. Depth to ground water ranges from 30 to 100 ft.
2. Completed in 1998. Four basins (1.8 to 3.5 acres), 12 cfs peak inflow.
3. Completed in 2003. Seven basins, 50 cfs peak inflow.
4. Completed in 2004. Three basins (7 to 11 acres), 60 cfs peak inflow.
5. Completed in 2001. Two pilot basins (7 acres each), three expansion basins (7 to 15 acres)
6. In pilot testing phase.
7. In feasibility phase.

The SDF View program calculates return flow after the recharge stops. The decay curve of return flow after recharge stops varies with the SDF value. A smaller SDF value results in a rapid decay in return flow volume, while a larger SDF value results in a more uniform decay in return flow volume. SDF values of 30, 40, 50, and 60 days were used in the analysis. These values would result in larger volumes of same season return flow.

There were not enough data available to identify specific sites and SDF properties for surface recharge. Site identification will require a site investigation, including drilling and aquifer testing to obtain estimates of the hydrogeologic properties. However, a screening of potential areas was conducted based on surficial geology, land cover, estimated aquifer properties, and distance buffers around the Yakima River and main tributaries.

Areas shown to be alluvium or unconsolidated sediments at the ground surface were initially identified as having potential for surface recharge. Refer to Figure 3-2 for the distribution of geologic units. Aquifer transmissivity is the product of the thickness of the aquifer unit and the hydraulic conductivity. The thickness of the aquifer unit was determined using Geographic Information System (GIS) maps developed as part of the USGS report on the hydrogeology of the Yakima River Basin (Jones, et al., 2006). The range of thicknesses was determined for the basins with unconsolidated sediments: Kittitas, Selah, Yakima, Toppenish and Benton. The maximum total thickness of the unconsolidated sediments in each basin is 790 feet for Kittitas, 290 feet for Selah, 350 feet for Yakima, 270 feet for Toppenish, and 870 feet for Benton (Jones, et al., 2006). The total thickness of saturated alluvium and unconsolidated sediments was based on an assumed depth to water of 40 feet. A depth to water of 40 feet represents the average maximum depth to water measured in the wells identified in Figure 3-6. Appendix A contains the USGS (Jones, et al., 2006) isopach maps for the various units.

The hydraulic conductivity (K) of alluvium and/or unconsolidated sediments in the Yakima River Basin ranges from 5.1 to 26 feet/day (Hansen, et al., 1994). Specific yield ranges from 0.03 to 0.2 (Whiteman, et al., 1994). Keeping the distance and the aquifer thickness constant, a low SDF factor is obtained using the minimum S (0.03) and maximum K (26 feet/day), and results in a rapid decay of return flow volumes after recharge stops. A high SDF factor is obtained using the maximum S (0.2) and minimum K (5.1 feet/day), and results in a more uniform decay of return flow volumes after recharge stops. Intermediate combinations (maximum S/maximum K and minimum S/minimum K) result in intermediate SDF values. These four combinations of aquifer properties were therefore used with the maximum aquifer thickness in each basin to evaluate the distance needed between an infiltration pond and the stream to achieve the four SDF values (Table 4-4).

TABLE 4-4

Estimated Range in Distance Between Stream and Infiltration Site to Achieve Optimum Same-Season Return Flows

Stream Depletion Factor (days)[2]	Range in Maximum Distance from Stream (feet)[1]				
	Above Parker Gauge		Below Parker Gauge		
	Kittitas	Selah	Yakima	Benton	Toppenish
30	760 - 4,400	440 - 2,600	490 - 2,800	800 - 4,600	420 - 2,400
40	880 - 5,100	510 - 2,900	560 - 3,300	920 - 5,400	480 - 2,800
50	980 - 5,700	570 - 3,300	630 - 3,700	1,000 - 6,000	540 - 3,200
60	1,100 - 6,300	620 - 3,600	690 - 4,000	1,100 - 6,600	590 - 3,500

Notes:

1. The range is based on the different combinations of specific yield and hydraulic conductivity using the maximum thickness of the unconsolidated materials in each basin. Figure 4-2 maps the maximum distance buffer for each sub-basin. For example, only land within 6,300 feet of a stream in the Kittitas Basin is shown on the map.

2. The stream depletion factor is used in the context of return flow or accretion to the river. The equation used to calculate the SDF value is

$$SDF = \frac{x^2 S}{T}$$, where

x = effective distance from the infiltration basin to the surface water source (ft)
S = specific yield (dimensionless)
T = transmissivity (ft^2/day)

A smaller SDF value results in a rapid decay in return flow volume, while a larger SDF value results in a more uniform decay in return flow volume. SDF values of 30, 40, 50, and 60 days were used in the analysis. These values would result in a larger volume of same season return flow.

4.4 POTENTIAL SURFACE RECHARGE AREAS

Areas suitable for surface infiltration will depend on surficial geology, SDF buffer distance, and land cover characteristics. The general areas that are expected to be suitable for surface recharge sites are shown on Figure 4-2. These locations were delineated based on the following:

- Surficial geology: The extent of the unconsolidated aquifers identified in the hydrogeologic mapping by Jones et al. (2006).

- Optimum SDF buffer distance: The maximum distance from the stream that would achieve an SDF value of between 30 and 60. Areas outside of this buffer will not achieve a SDF value of between 30 and 60 under the range of potential aquifer properties and thicknesses present in each basin. An SDF value of between 30 and 60 is optimum because it provides a larger same-season return flow to the stream.

Figure 4-2 shows that the largest areas with optimum recharge conditions are located in the Kittitas, Yakima and Toppenish sub-basins.

Land cover was also considered in evaluating where suitable recharge sites could be located using the National Land Cover Dataset (USGS, 1999). Land cover was grouped into general categories of natural vegetation, barren, commercial/industrial/transportation, high intensity residential, low intensity residential, nonirrigated agriculture, orchard/vineyard, other irrigated agriculture, fallow, water, and wetland (Figure 4-3). Areas that are currently classified as natural vegetation, nonirrigated agriculture, or fallow are considered more likely to be suitable for conversion to infiltration ponds.

Figures 4-4, 4-5, 4-6, and 4-7 show the surficial geology within the SDF buffer distance in the Kittitas, Selah, Yakima, Benton, and Toppenish sub-basins. The locations of existing wells and the range in depth to water are also provided on the maps. The areas along Taneum Creek, Manastash Creek, Yakima River, Caribou Creek, Coleman Creek, Naneum Creek, and Swauk Creek have been identified in the Kittitas sub-basin as potential surface recharge areas (Figure 4-4). The buffer area contains a large amount of natural vegetation and other irrigated agriculture.

Areas along the Yakima River, Wenas Creek, Naches River, and Cowiche Creek have been identified in the Selah sub-basin as potential surface recharge areas (Figure 4-5). The buffer area contains a large amount of natural vegetation and orchard/vineyard land.

Areas along the Yakima River and Ahtanum Creek have been identified in the Yakima sub-basin as potential surface recharge areas (Figure 4-5). The buffer area contains a large amount of natural vegetation and orchard/vineyard land.

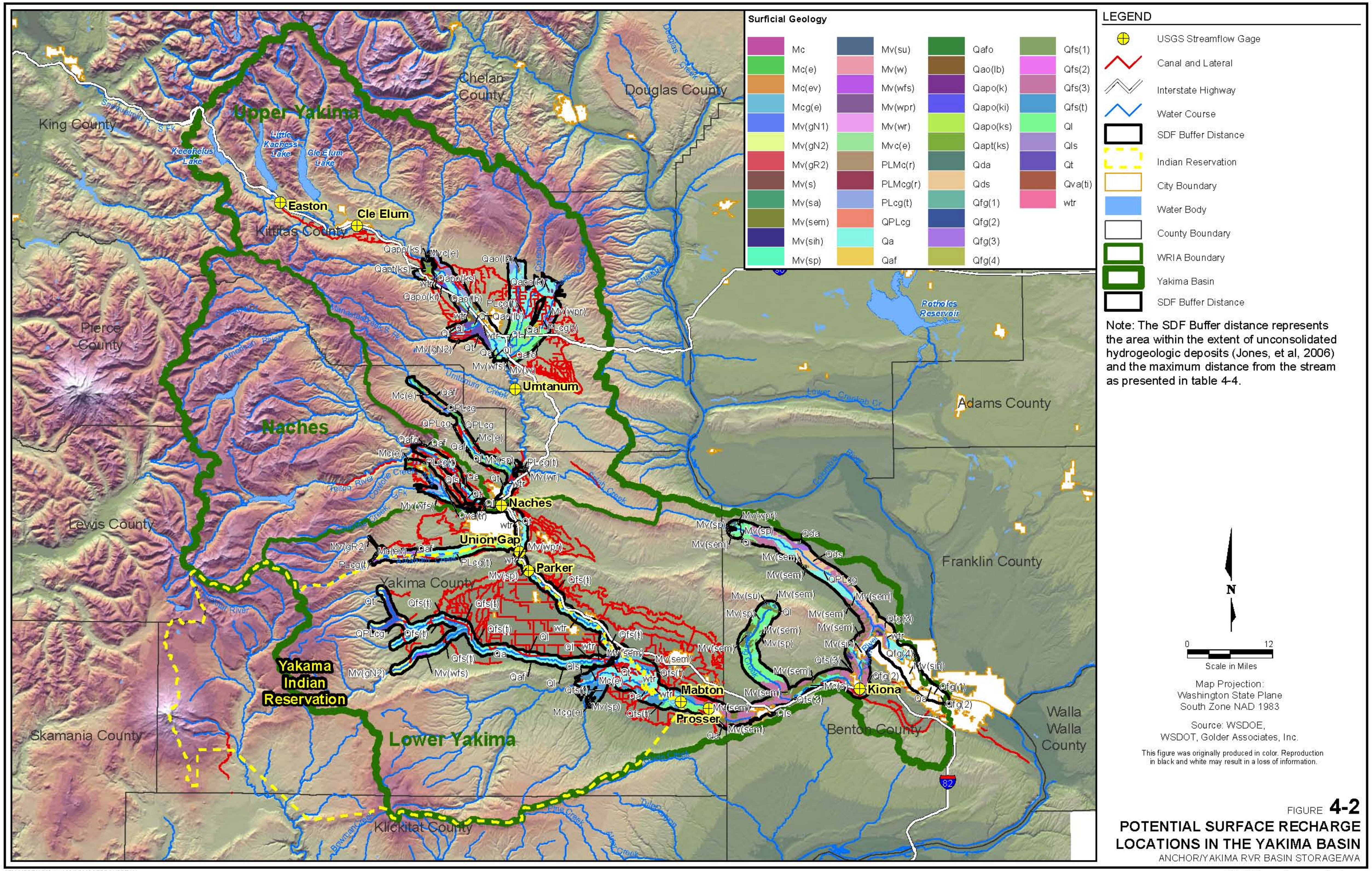

FIGURE 4-2
POTENTIAL SURFACE RECHARGE LOCATIONS IN THE YAKIMA BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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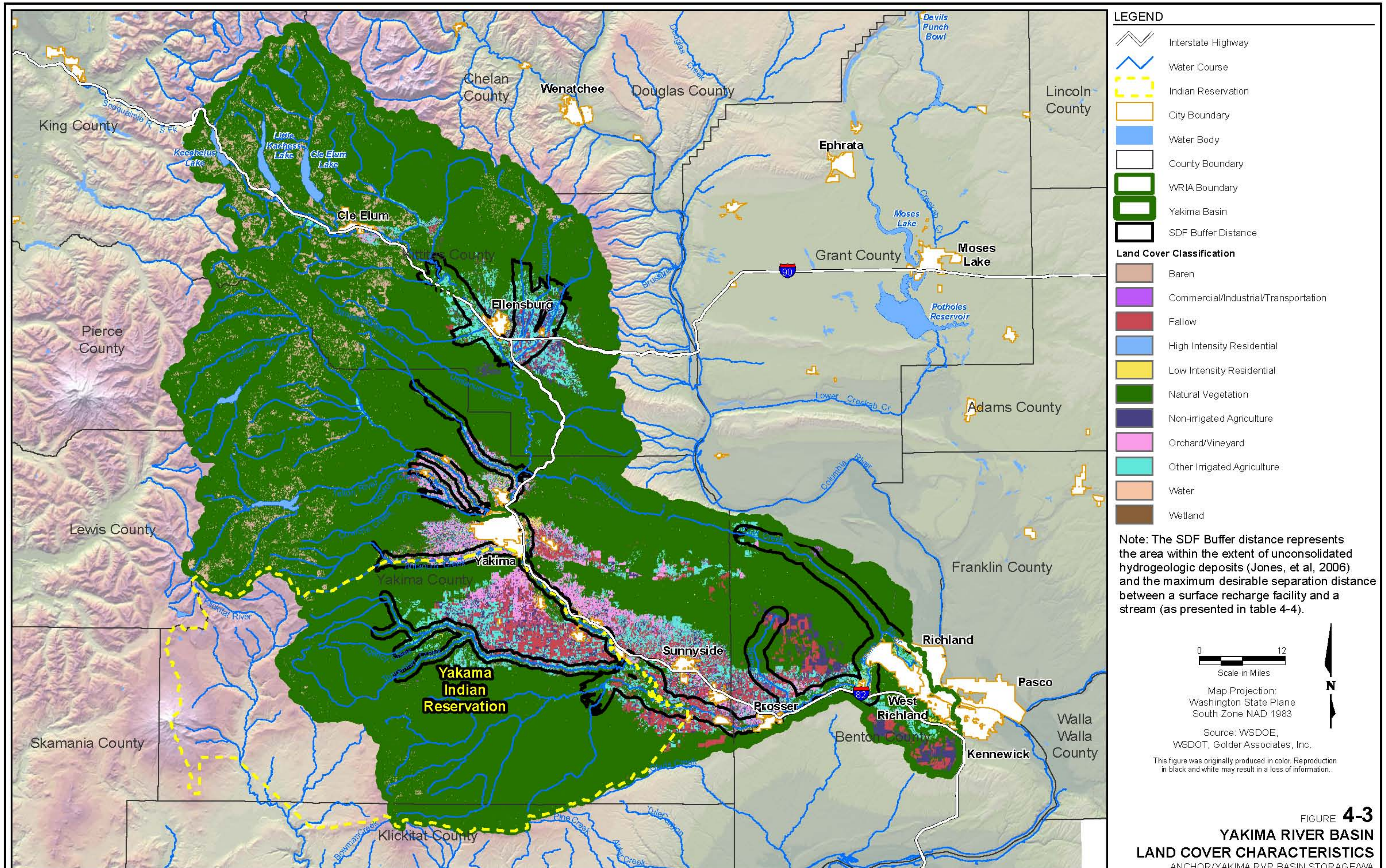

FIGURE **4-3**
YAKIMA RIVER BASIN
LAND COVER CHARACTERISTICS
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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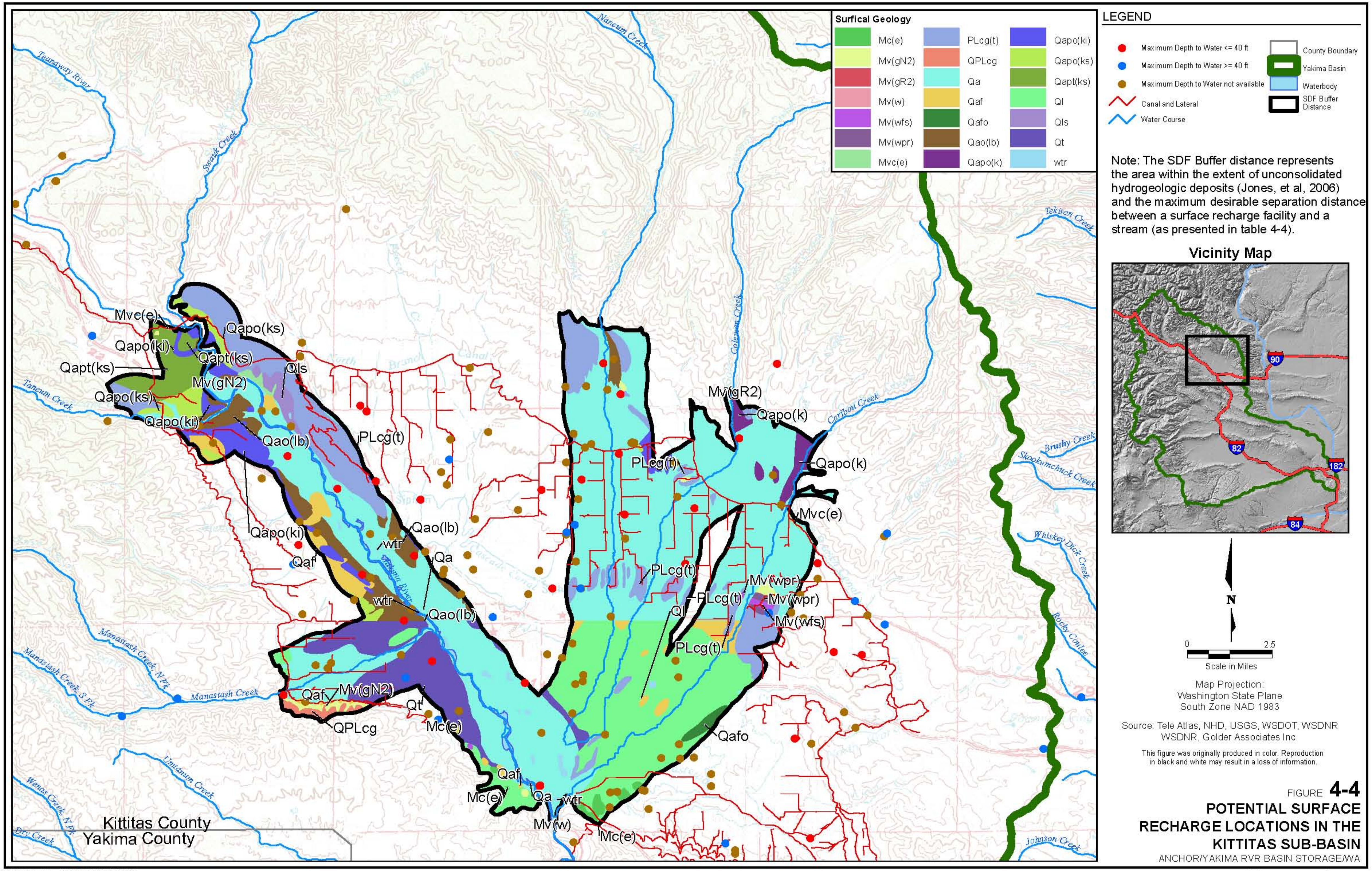
Surfical Geology
Mc(e)
Mv(gN2)
Mv(gR2)
Mv(w)
Mv(wfs)
Mv(wpr)
Mvc(e)
PLcg(t)
QPLcg
Qa
Qaf
Qafo
Qao(lb)
Qapo(k)
Qapo(ki)
Qapo(ks)
Qapt(ks)
Ql
Qls
Qt
wtr
LEGEND
Maximum Depth to Water <= 40 ft
Maximum Depth to Water >= 40 ft
Maximum Depth to Water not available
Canal and Lateral
Water Course
County Boundary
Yakima Basin
Waterbody
SDF Buffer Distance
Note: The SDF Buffer distance represents the area within the extent of unconsolidated hydrogeologic deposits (Jones, et al, 2006) and the maximum desirable separation distance between a surface recharge facility and a stream (as presented in table 4-4).
Vicinity Map
90
82
182
84
N
0
2.5
Scale in Miles
Map Projection:
Washington State Plane
South Zone NAD 1983
Source: Tele Atlas, NHD, USGS, WSDOT, WSDNR
WSDNR, Golder Associates Inc.
This figure was originally produced in color. Reproduction in black and white may result in a loss of information.
FIGURE 4-4
POTENTIAL SURFACE RECHARGE LOCATIONS IN THE KITTITAS SUB-BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates
Kittitas County
Yakima County
Teanaway River
Swauk Creek
Naneum Creek
Coleman Creek
Caribou Creek
Taneum Creek
Manastash Creek
Umtanum Creek
Wenas Creek, N Fk
Dry Creek
Tekison Creek
Brushy Creek
Skookumchuck Creek
Whiskey Dick Creek
Rocky Coulee
Johnson Creek
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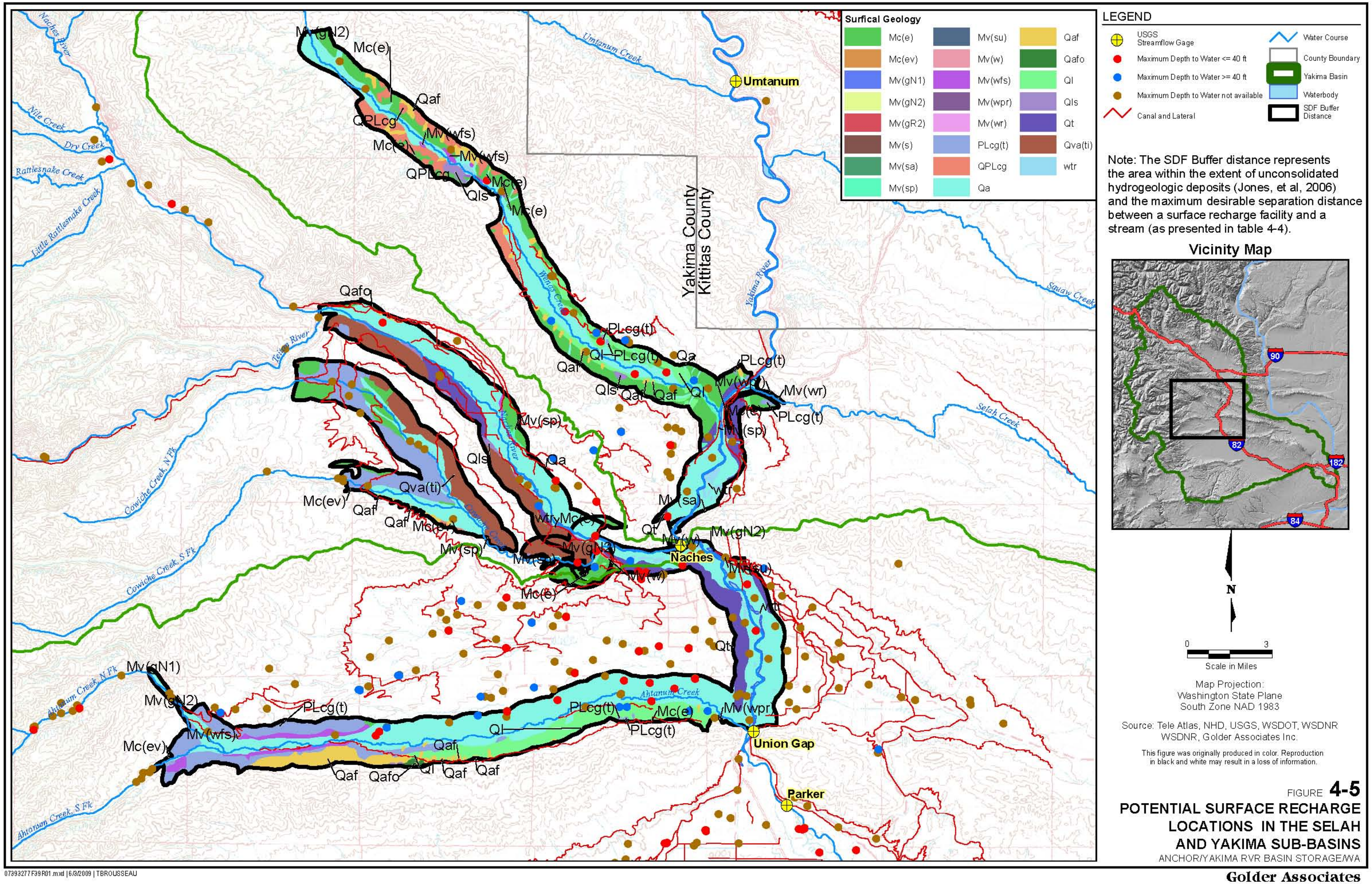
Surfical Geology
Mc(e)
Mc(ev)
Mv(gN1)
Mv(gN2)
Mv(gR2)
Mv(s)
Mv(sa)
Mv(sp)
Mv(su)
Mv(w)
Mv(wfs)
Mv(wpr)
Mv(wr)
PLcg(t)
QPLcg
Qa
Qaf
Qafo
Ql
Qls
Qt
Qva(ti)
wtr
LEGEND
USGS Streamflow Gage
Maximum Depth to Water <= 40 ft
Maximum Depth to Water >= 40 ft
Maximum Depth to Water not available
Canal and Lateral
Water Course
County Boundary
Yakima Basin
Waterbody
SDF Buffer Distance
Note: The SDF Buffer distance represents the area within the extent of unconsolidated hydrogeologic deposits (Jones, et al, 2006) and the maximum desirable separation distance between a surface recharge facility and a stream (as presented in table 4-4).
Vicinity Map
90
82
182
84
N
0
3
Scale in Miles
Map Projection:
Washington State Plane
South Zone NAD 1983
Source: Tele Atlas, NHD, USGS, WSDOT, WSDNR
WSDNR, Golder Associates Inc.
This figure was originally produced in color. Reproduction in black and white may result in a loss of information.
Umtanum
Naches
Union Gap
Parker
Yakima County
Kittitas County
Umtanum Creek
Naches River
Nile Creek
Dry Creek
Rattlesnake Creek
Little Rattlesnake Creek
Tieton River
Cowiche Creek, N Fk
Cowiche Creek, S Fk
Ahtanum Creek, N Fk
Ahtanum Creek, S Fk
Ahtanum Creek
Yakima River
Squaw Creek
Selah Creek
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FIGURE 4-5
POTENTIAL SURFACE RECHARGE LOCATIONS IN THE SELAH AND YAKIMA SUB-BASINS
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates