MULTIPURPOSE WATER STORAGE SCREENING ASSESSMENT REPORT

WRIA 30

Prepared for: WRIA 30 Planning Unit

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1 Introduction

This report presents the findings from a screening-level multipurpose water storage assessment for Water Resource Inventory Area 30 (WRIA 30), the Klickitat River watershed. Like other parts of Washington State, WRIA 30 likely has adequate water on an annual basis to meet current instream and out-of-stream water needs and support some growth. However, the water is not available uniformly throughout the entire year. Precipitation and streamflows are highest in the winter wet season when water demand is lowest. Conversely, precipitation and streamflows are lowest in the summer, when water demand is highest. One solution to this timing problem with water availability is to store water when there is excess runoff and stream flows in the winter, and deliver it during the summer low-flow period when it is needed for people and fish. Winter peak flows do provide benefit to the watershed, therefore reduction in peak flows is a potential environmental impact to be evaluated for a prospective storage project.

No formal studies of water storage options for WRIA 30 have been identified. However, the City of Goldendale's Watershed Management Plan (Gray and Osborne 1998) included preliminary evaluation of an additional surface water reservoir to support municipal supply. The evaluation identified potential candidate sites in the upper Little Klickitat subbasin, below the City's Simcoe Mountain Springs source, on two surface water drainages – the West Prong of the Little Klickitat River and Butler Creek. The City has not pursued further study of a reservoir option.

This assessment reviews potential water storage opportunities within defined priority areas of WRIA 30 as a first step in evaluating whether storage can be used to more efficiently manage the available water resources in the watershed. This assessment was prepared by Aspect Consulting LLC, under subcontract to Watershed Professionals Network (WPN). This assessment was funded under Grant number G0300156 obtained by the WRIA 30 Planning Unit, with Klickitat County as lead agency, from the Washington State Department of Ecology (Ecology) under the Watershed Planning Act.

1.1 Results from Level 1 Water Quantity Assessment

The available information from the Phase 2 Level 1 water quantity assessment (WPN 2003), as per RCW 90.82.070, indicates no apparent long-term trends in either annual discharge or annual low flows in the mainstem Klickitat River. Snowmelt from Mount Adams contributes water to the Klickitat River in its upper reaches, which sustains flows in the mainstem through the dry summer months. There are no apparent long-term trends in total annual discharge of the Little Klickitat River at Wahkiacus. However, a significant declining trend in annual low flows was observed at this location. Streamflow records in the other subbasins were of insufficient duration or quality to evaluate trends.

Ecology has listed the following WRIA 30 waterbody segments on its 1998 Section 303(d) list for impaired water quality:

Table 1 – Ecology 1998 303(d) Listings for WRIA 30

Waterbody	Parameter	TRS	Subbasin	ID No.
Blockhouse Creek	Instream Flow	T4N R15E S17	Little Klickitat	ID95ML
Bloodgood Creek	Instream Flow	T4N R16E S17	Little Klickitat	XU61D0
Bowman Creek	Instream Flow	T5N R14E S35	Little Klickitat	TN94DB
Butler Creek	Temperature	T5N R17E S17	Little Klickitat	YU86SG
Little Klickitat River	Instream Flow	T4N R14E S9	Little Klickitat	AY21LB
Little Klickitat River	Temperature	T4N R14E S9	Little Klickitat	AY21LB
Little Klickitat River	Instream Flow	T4N R15E S28	Little Klickitat	AY21LB
Little Klickitat River, East Prong	Temperature	T5N R17E S3	Little Klickitat	PW77VQ
Little Klickitat River, East Prong	Temperature	T5N R17E S9	Little Klickitat	PW77VQ
Little Klickitat River, East Prong	Temperature	T5N R17E S10	Little Klickitat	PW77VQ
Little Klickitat River, East Prong	Temperature	T5N R17E S16	Little Klickitat	AG85MX
Little Klickitat River, East Prong	Temperature	T6N R17E S35	Little Klickitat	PU81CT
Little Klickitat River, West Prong	Temperature	T5N R17E S18	Little Klickitat	XU61EK
Mill Creek	Instream Flow	T4N R15E S5	Little Klickitat	FF43IZ
Swale Creek	Instream Flow	T4N R14E S19	Swale Creek	XN32NH
Swale Creek	Temperature	T4N R14E S19	Swale Creek	XN32NH

TRS: Township, Range, Section.

In addition, EPA established a TMDL based on dilution requirements for the City of Goldendale's wastewater treatment plant discharge to address dissolved oxygen and chlorine in the Little Klickitat River (T4N R16E section 19) (ID no. AY21LB). Ecology is in the process of developing a TMDL for temperature in the Little Klickitat River.

As Table 1 indicates, all of the 303d-listed waterbodies in WRIA 30 occur within the Little Klickitat and Swale Creek subbasins. Figure 1 depicts the location of the six subbasins comprising WRIA 30.

In addition, the existing water use estimates from the Level 1 Assessment indicate that the Little Klickitat and Swale Creek subbasins have the two greatest annual water uses per acre (normalized water use) of any subbasin in WRIA 30. These two subbasins also have lower annual average precipitation than does the upper watershed (Upper or Middle Klickitat subbasins).

Based on the collective information from the Level 1 water quantity assessment, opportunities for water storage in WRIA 30 are focused initially within the Little Klickitat and Swale Creek subbasins. Focusing this screening assessment solely on these two priority subbasins is consistent with the 3-month project schedule required under Grant G0300156.

1.2 Assessment Objectives

The overriding objective of this water storage screening assessment is to identify water storage opportunities that could potentially meet multiple water needs in the Little Klickitat and/or Swale Creek subbasins. This assessment does not define water need priorities for those subbasins, or for the larger WRIA 30 watershed. Rather, it identifies a range of prospective storage opportunities in the two subbasins based on the subbasin physical characteristics as currently understood, irrespective of water needs. Because watershed hydrology, geology, topography, fish distribution and habitat, land ownership, and other factors may limit the number of feasible opportunities for water storage in any watershed, a screening-level identification of those opportunities is a useful first step in the process of water storage planning at the watershed scale. Water needs that could potentially be addressed through water storage can then be matched up with the feasible storage opportunities.

Specific objectives of this screening assessment are to:

1. Identify, qualitatively, potential sources and timing of excess water available for storage in these two subbasins;
2. Refine conceptual model of groundwater-surface water interactions in these two subbasins to guide selection of potentially feasible storage options;
3. Identify a range of options for storage of available excess water; and
4. Identify geographic locations where one or more of these options could be implemented in these two subbasins.

As noted in the Level 1 Assessment, few hydrologic data exist for the Swale Creek and Little Klickitat subbasins. Therefore, a focus of this screening assessment was field data collection to improve understanding of potential sources of excess winter water and the interaction between groundwater and streamflows in these subbasins. The potential benefits afforded by water storage in WRIA 30 can likely be realized predominantly during the dry summer months, therefore dry season hydrologic conditions are of greatest interest. Consequently, data would optimally be collected both during the peak dry season (August/September 2003) in addition to the spring timeframe (April 2003). Additional data collection during the dry season was included in the scope of work for the grant application to Ecology for this storage assessment, with the understanding that approval for a time extension is required from Ecology. Given the uncertainty with funding beyond the current biennium, such an approval is uncertain at this time. Therefore, this report includes the data collected in April 2003, as authorized under the grant. If additional data are collected in the late summer 2003 under this grant, those data would be presented in an addendum to this report.

This screening assessment does not prioritize or select water storage project(s) to carry forward for implementation under the Watershed Planning Act. Rather, those decisions will be made subsequently by the WRIA 30 Planning Unit using information provided in this report and from other sources, in combination with the Planning Unit's defined water need priorities. In defining water needs that may be met through storage, it is important to

note that there is a state statutory preference for storage projects that serve multiple purposes rather than a single purpose (RCW 90.54.020).

1.3 Overview of Conceptual Water Storage Opportunities

There are multiple methods that can be used to store water, depending on site-specific conditions. This section provides a brief overview of four conceptual storage options available for consideration by the WRIA 30 Planning Unit. The most basic division of storage options is whether the water is stored above ground in a constructed surface water reservoir, or underground in a naturally occurring aquifer. This screening assessment includes evaluation of two conceptual options using subsurface storage (enhanced groundwater recharge; aquifer storage and recovery) and two using surface storage (on-channel dam; off-channel impoundment). In the following four subsections, each of the four conceptual storage opportunities are outlined in terms of:

- Potential uses of water stored by that method;
- Relative pros and cons in terms of potential environmental effects; permitting, construction, or operation/maintenance; and relative cost;
- Data gaps to be addressed if the Planning Unit identifies an opportunity for further evaluation based on a defined water need.

Additional detail regarding application of each conceptual option to each priority subbasin is included in Sections 3 and 4 of this report.

1.3.1 Enhanced Groundwater Recharge

Using excess water to increase groundwater recharge, without active recovery of that additional stored water, is referred to in this assessment as enhanced groundwater recharge. Such recharge could be achieved through surface spreading, constructed infiltration facilities, or shallow wells. The extra recharge would then achieve benefit through greater volumes of natural groundwater discharge. To recover the stored water other than by natural discharge would be ASR (see Section 1.3.2). Currently, Washington state law makes no provisions regarding enhanced groundwater recharge projects (Ecology 2001a).

It is expected that enhanced recharge may best be applied in areas where deposits of unconsolidated alluvium occur in broad, flat stream valleys. This would be particularly true where instream flow augmentation is a desired use of the stored water. In such a setting, structures designed to detain water and prolong the time available for its infiltration could be placed off the main channel, within the floodplain. The intent would be to allow enhanced infiltration within the floodplain during winter/spring peak flow events, without impairing stream channel function during low-flow conditions. Grading of the floodplain or construction of infiltration structures might be required to ensure that the infiltration occurs within intended areas, and does not create flooding problems in unintended areas. Assuming late-season instream flow augmentation is the intended use, the infiltration area(s) would be positioned such that subsequent discharge of this stored water into the stream would occur late-season. This positioning would be determined based on estimated groundwater flow directions and rates. Because the available storage volume in such alluvial deposits is limited to the thickness of unsaturated material above

the winter water table, storage volumes from any one enhanced recharge project would likely be small.

Apart from instream uses, there are many water rights in the Little Klickitat subbasin for collection of spring discharge from the Simcoe Volcanics and use of that water for various out-of-stream uses. Using excess water to enhance recharge to a bedrock (basalt) aquifer supplying such discharge could make additional water available for out-of-stream or instream uses. However, this would require identifying an area near a source for excess water where the basalts have capacity to store more water, are within some reasonable distance from groundwater discharges naturally from a basalt aquifer, and are located where additional discharge would be beneficial. Such a project would first identify an existing groundwater discharge zone where enhancement is desired to meet a defined need, then identify the area supplying recharge to that discharge. It could be possible to inject recharge water into a confined aquifer under pressure. Overall, we expect that designing an enhanced recharge project would be more complex using basalts than using alluvial deposits along streams.

Potential Uses

- Instream flow augmentation.
- Multiple out-of-stream uses if possible to collect increased spring discharge.

Pros

- Stored water is maintained at low temperature and is protected from surface contamination and evaporative loss.
- Potentially the simplest and lowest cost option to permit and implement.

Cons

- Likely limited to small water volumes.
- Requires appropriate hydrogeologic setting and accurate knowledge of the timing between groundwater recharge and discharge to ensure intended benefit is achieved.
- Out-of-stream use complicated by potential difficulty in collecting spring discharge that may be diffuse.
- May not be possible to 'recover' all of stored water in manner hoped for.

Data Gaps

Additional information recommended if the Planning Unit decides to pursue further evaluation of this storage opportunity to meet defined water needs:

- Identify prospective sites for enhanced recharge, based on locations where additional groundwater discharge is desired and site hydrogeologic conditions.
- Quantify volumes and timing of excess water potentially available for storage by establishing and continuously monitoring stream gages near prospective enhanced recharge sites.

- For prospective sources of excess winter water, evaluate timing of fish use and habitat value of the streams to determine window in which diversion could be permitted.
- Evaluate changes necessary in existing water rights and other permitting requirements specific to the project.
- Evaluate land ownership, access and existing infrastructure, and potential for impacts to the environment (SEPA) or other water rights.
- Evaluate funding options.

1.3.2 Aquifer Storage and Recovery (ASR)

Water can also be stored underground, where an aquifer serves as a subsurface reservoir. Aquifer storage and recovery (ASR) refers to temporarily storing water in an aquifer for later recovery and use. In the 2000 session, the Washington State Legislature expanded the definition of "reservoir" in RCW 90.03.370 to include "any naturally occurring underground geological formation where water is collected and stored for subsequent use as part of an underground artificial storage and recovery project." In March 2003, Ecology adopted WAC 173-157, which establishes the standards for review of applications for ASR projects and standards for mitigation of potential adverse impacts to groundwater quality or the environment. In eastern Washington, the cities of Kennewick, West Richland, Walla Walla, and Yakima are all evaluating the feasibility of ASR to help meet future water demands.

Most water sources used to recharge an aquifer for ASR will require some degree of water quality treatment prior to its storage. At a minimum, the recharged water must have minimal turbidity to avoid clogging the ASR well and the aquifer around the well. In addition, recharge water quality cannot exceed applicable groundwater quality standards, or degrade ambient groundwater quality in the storage aquifer. Typically in ASR applications, a greater volume of water is recharged to the aquifer for storage than is subsequently withdrawn for beneficial use, because some recharge water is "lost" to mixing with the ambient groundwater. This can lead to an increase in the volume of groundwater in the storage aquifer through successive ASR cycles. As is the case for a surface water reservoir, ASR requires two water rights – a reservoir permit and a secondary permit to use the stored water.

Potential Uses

- Multiple - provide water for out-of-stream uses and benefit summer instream flows.

Pros

- Range of uses is versatile – same as for any groundwater withdrawal.
- Maintains stored water at low temperature and protected from surface contamination and evaporative loss.
- Less land required and less surface disruption than surface reservoir systems.

- Because the volume of water recovered is typically less than the volume stored, allows for gradual replenishment of aquifer.

Cons

- Limited to areas with appropriate hydrogeologic setting in proximity to available excess surface water.
- Source water requires water quality treatment prior to storage.
- Requires significant pilot testing to demonstrate feasibility.
- Considerable operation and maintenance (O&M) effort to ensure appropriate timing and volumes of storage and recovery, ensure ASR well doesn't clog, etc.

Data Gaps

Additional information recommended if the Planning Unit decides to pursue further evaluation of this storage opportunity to meet defined water needs:

- Evaluate hydrogeologic suitability for ASR in areas near potential excess water source(s) and where property ownership might allow for ASR.
- Quantify volumes and timing of excess water potentially available for storage by establishing and continuously monitoring stream gages near prospective ASR sites.
- For prospective sources of excess winter water, evaluate timing of fish use and habitat value of the streams to determine window in which diversion could be permitted.
- Evaluate water quality compatibility between prospective surface water source and groundwater in storage aquifer.
- Evaluate changes necessary in existing water rights and other permitting requirements specific to the project.
- Evaluate land ownership, access and existing infrastructure, and potential for impacts to the environment (SEPA) or other water rights.
- Evaluate funding options.

1.3.3 On-Channel Dam

There are currently more than 1,100 surface water dams in Washington State that store more than 10 acre-feet of water, with about 380 dams used primarily for water supply storage (Ecology 2001b). On-channel dams and reservoirs are sited on major streams and are filled directly by flow from the upstream watershed. The stored water could be held and released downstream to augment summer low flows and be diverted for out-of-stream uses. Alternatively, the stored water could be piped directly from the reservoir for out-of-stream uses. On-channel dams are typically constructed in deeply incised bedrock channels. Because the resulting reservoir is relatively deep with small surface area, it helps maintain the stored water at lower temperature than a shallow off-channel reservoir

of comparable volume. The ability to allow fish passage could be engineered into the design of a dam, if warranted.

For this screening assessment, dam construction is only considered an option across non-fish-bearing stream reaches, unless an overall net benefit to aquatic resources in the larger watershed could be demonstrated. Such a determination would require detailed analysis and is beyond the scope of this screening assessment.

Potential Uses

- Multiple - provide water for out-of-stream uses and instream flows. If stored water becomes too warm to improve instream conditions downstream, could evaluate piping stored water to replace existing stream diversions for non-temperature-dependent out-of-stream uses (e.g., irrigation), thus improving summer instream flows while continuing to meet the existing out-of-stream need. Could also be used for fire suppression in higher elevation forested areas.

Pros

- Potentially benefit summer instream flow and temperature conditions, and provide water for out-of-stream uses.
- Likely amenable for greatest storage volumes.
- Likely has lower cost per volume of water stored than off-channel storage.

Cons

- Dam locations limited to non-fish-bearing waters, which may greatly limit feasible locations.
- Greatest instream impact.
- Greatest permitting difficulty of the four conceptual options considered here.
- Stored water may be temperature-impaired by time of its release in late summer.
- Stored water lost to evaporation and subsurface seepage.
- Sedimentation behind dam.

Data Gaps

Additional information recommended if Planning Unit decides to pursue further evaluation of this storage opportunity to meet defined water needs:

- Accurately define fish-bearing/valuable habitat stream reaches to eliminate those reaches that are not options for an on-channel dam based on net environmental detriment.
- Dam siting evaluation of prospective on-channel storage sites, including field inspection to evaluate: land ownership, valley topography (reservoir volume to surface area ratio), geology, habitat potentially flooded, access and existing infrastructure, etc.

- Quantify volumes and timing of excess water potentially available for storage by establishing and continuously monitoring stream gages at prospective dam sites.
- Evaluate changes necessary in existing water rights and other permitting requirements specific to the project.
- Evaluate potential for impacts to the environment (SEPA) or other water rights.
- Evaluate funding options.

1.3.4 Off-Channel Impoundment

Off-channel impoundments are sited outside the main river valley, completely off-stream or possibly on an intermittent stream. Water to fill the reservoir can be diverted by gravity or pumping from an adjacent stream. Examples of off-channel impoundments include natural topographic depressions that are dammed to retain water; constructed ponds, basins, or tanks; and wetlands - either natural or constructed. Numerous stock watering ponds in Klickitat County are constructed off-channel. Off-channel impoundments may represent the best storage opportunities for including habitat enhancement as a component of the project (e.g., developing wetlands, opening side channel environments, eliminating dikes, etc.).

Potential Uses

- Multiple - provide water for out-of-stream uses and instream flows. As discussed above for an on-channel dam, if stored water is too warm to improve instream conditions, could use the stored water to replace existing stream diversions for non-temperature-dependent out-of-stream uses. If of sufficient size and depth, could also be used for fire suppression.

Pros

- Potentially benefit summer instream flow conditions, and provide water for out-of-stream uses.
- Generally flexible in terms of location and sizing. Can be located and sized to meet small agricultural irrigation needs, for which additional funding may be available as an irrigation improvement.
- Could be engineered to include wetlands or other habitat elements, thus providing additional environmental benefit.
- Relatively little instream impact, thus easier to permit than on-channel.

Cons

- Likely involves greatest land area and surface disruption.
- Stored water likely temperature-impaired by late summer. However, this may be mitigated by reintroducing the stored water back into the stream channel via subsurface means, thus providing cooling.
- Likely has higher cost per volume of water stored than on-channel storage.

- Stored water lost to evaporation and, if unlined, to subsurface seepage.
- Sedimentation of impoundment.

Data Gaps

Additional information recommended if the Planning Unit decides to pursue further evaluation of this storage opportunity to meet defined water needs:

- Quantify volumes and timing of excess water potentially available for storage by establishing and continuously monitoring stream gages at prospective dam sites.
- For prospective sources of excess winter water, evaluate timing of fish use and habitat value of the streams to determine window in which diversion could be permitted;
- Because of the potentially large land requirements, define land ownership around streams representing prospective excess water sources and evaluate viability of land acquisition.
- Siting evaluation of prospective off-channel storage sites, including field inspection to evaluate topography, geology, existing infrastructure and access, etc.
- Evaluate changes necessary in existing water rights and other permitting requirements specific to the project.
- Evaluate potential for impacts to the environment (SEPA) or other water rights.
- Evaluate funding options.

Table 2 is a matrix briefly summarizing these four conceptual water storage options. Whether these potential benefits or drawbacks are realized for a specific storage project would depend on the site specifics of that project.

Table 2 – Summary of Conceptual Water Storage Opportunities

Option	Mechanism	Potential Benefits	Potential Drawbacks
Enhanced Groundwater Recharge	• Detain/spread excess water to increase recharge. • No active recovery. • Stored water discharges naturally.	• Increase late-season instream flows. • No evaporative loss. • Maintain low water temperature. • Reservoir protected from surface influence. • Easiest to permit and implement. • Low cost.	• Limited to small water volumes. • Not conducive to multiple uses. • Need appropriate hydrogeology. • Need to know timing from recharge to discharge accurately. • May not 'recover' all of stored water in manner hoped for.
Aquifer Storage and Recovery (ASR)	• Store excess water in aquifer, typically via wells. • Recover stored water by pumping. • Typically more water is stored than recovered each year.	• Amenable to multipurpose uses. • Little surface disruption. • No evaporative loss. • Maintain low water temperature. • Reservoir protected from surface influence. • Can restore/enhance aquifer capacity.	• Need appropriate hydrogeology. • Water treatment prior to storage. • Requires significant pilot testing. • Considerable O&M. • Well can clog.
On-Channel Dam	• On-channel dam filled directly with excess upstream water • Water released back into stream or pump out.	• Amenable to multipurpose use. • Potentially greatest storage volume. • Lower capital and O&M cost per volume stored than off-channel.	• Limited to non-fish-bearing waters. • Greatest instream impact. • Greatest permitting hurdles. • Possible high water temperature. • Evaporative and seepage losses. • Sedimentation behind dam.
Off-Channel Impoundment	• Divert excess water to surface reservoir away from stream. • Pump/drain water for use. • Typically shallow.	• Less instream impact than on-channel. • Flexible in terms of location and size. • Could be engineered to provide additional habitat benefit.	• High water temperature, thus limited to out-of-stream uses. • Difficult to site – takes large land area. • Higher cost per volume stored than on-channel. • Evaporative and seepage losses. • Impoundment sedimentation.

Table 3 presents a range of water volumes (acre-feet) that could be stored under a range of average flow rates and time frames for water detention/diversion, irrespective of storage option. In reality, the runoff hydrograph will not be a constant with time. Based on gaging data presented in the Level 1 Assessment, runoff in the Little Klickitat subbasin typically starts in October or November, increases rapidly in December, peaks in February or March, and begins declining by May (as shown on Figure 7). The flow rates in Table 3 are constant values that represent an average of this temporal variability. This table merely provides a point of reference for subsequent discussions of excess water volumes in this report. For example, diverting/detaining an average of 10 cfs continuously for 5 months provides a storage volume of approximately 3,000 acre-feet. Alternatively, this table can be used to evaluate the approximate water release available

for a given stored volume (e.g., 3,000 acre-feet stored provides an average 10 cfs release for 5 months, assuming negligible loss from the reservoir). Tabulation of these numbers does not indicate that excess flows of such magnitude and/or duration exist, or are available for storage, in the two priority subbasins.

Table 3 – Acre-Feet of Water Stored Under Variable Flow (cfs) and Timing (Month) Scenarios

		Months of Water Diversion					
		0.5	**1**	**2**	**3**	**4**	**5**
Average cfs Diverted	**1**	30	60	121	181	242	302
	5	151	302	605	907	1,210	1,512
	10	302	605	1,210	1,815	2,420	3,025
	15	454	907	1,815	2,722	3,630	4,537
	20	605	1,210	2,420	3,630	4,840	6,050
	25	756	1,512	3,025	4,537	6,050	7,562
	30	907	1,815	3,630	5,445	7,260	9,074
	35	1,059	2,117	4,235	6,352	8,469	10,587
	40	1,210	2,420	4,840	7,260	9,679	12,099
	45	1,361	2,722	5,445	8,167	10,889	13,612
	50	1,512	3,025	6,050	9,074	12,099	15,124

As defined water needs have not yet been identified, each of the four conceptual storage options are evaluated in Sections 3 and 4 of this report in general terms for each of the priority subbasins. These sections also include a preliminary screening of generalized geographic areas where each option could be considered in each subbasin.

By screening each of the four conceptual opportunities for each subbasin in terms of their perceived relative merits, potential storage opportunities in each subbasin are not prematurely eliminated from consideration in this initial screening assessment. Therefore, the Planning Unit retains the greatest flexibility in matching potential storage opportunities to priority water needs that it may subsequently identify.

Note that storage opportunities discussed in this report are assumed to be implemented by the WRIA 30 Planning Unit under the Watershed Planning Act. This is not to imply that private landowners and/or public entities could not evaluate and pursue water storage projects in WRIA 30 independently of the Planning Unit.

1.3.5 Permitting

Regulatory review and approval of prospective water storage projects usually involve multiple permits. An overview of some of the major permits and approvals that may be required for a water storage project is provided below (modified from Ecology 2001b):

Environmental Review

Water storage projects that require local, state or federal approval require environmental review under the State Environmental Policy Act (SEPA) and/or the federal National Environmental Policy Act (NEPA). Environmental review is not a permit per se, but is intended to ensure that environmental values are considered during decision-making by government agencies. This review involves identifying and evaluating probable effects for all elements of the environment. Water storage projects will likely require the preparation of an environmental impact statement (EIS).

JARPA Permits

Numerous permits may be required for any water storage project that involves working in or near state waters. These permits are typically applied for through the Joint Aquatic Resource Permits Application (JARPA). All storage options considered in this screening assessment would likely require a Hydraulic Project Approval (HPA) from the Washington Department of Fish and Wildlife (WDFW). This permit is required for any project that includes construction or other work that will use, divert, obstruct, or change the natural flow or bed of any fresh or salt water of the state. Any project involving placement of a structure within waters of the U.S. would require an Army Corps of Engineers 404 permit. Any instream diversion structure would need to comply with WDFW regulations to ensure fish are not trapped or otherwise harmed by it.

Fish and Wildlife Mitigation Policy

WDFW has a formal policy related to mitigation that may be applicable to proposed water storage projects. The policy is applied by WDFW when issuing or commenting on environmental permits. The stated goal of the policy is to achieve no loss of habitat function and value. It lists the guiding principles for making decisions on appropriate mitigation activities, required elements of mitigation plans and appropriate legal documentation.

State Water Rights/Reservoir Permits

Under the Washington Water Code, there are three possible authorizations required for surface-water storage projects:

- A water right permit or certificate is required to divert or withdraw water to an off-channel reservoir. On-channel reservoirs do not require this authority.
- A reservoir permit or certificate is required to impound and store water if the reservoir is storing more than 10 acre-feet in volume or if it is 10 or more feet deep at its deepest point.
- A secondary permit(s) may be necessary for using reservoir water outside the reservoir. A secondary permit to beneficially use stored water is not required where an existing water right for the source of the stored water authorized the beneficial use. When practical, the authorizations to divert or withdraw public waters, to store water within a reservoir, and to use stored water outside the reservoir are combined into a single document.

For storing water underground in an aquifer (ASR), a water right permit is also required to divert or withdraw water to storage. Under legislation recently passed, the code now

allows application for aquifer reservoir permits similar to applying for a surface reservoir permit. A secondary permit(s) is also required to put the stored ASR water to beneficial use. Note that storage, by itself, is not a beneficial use of water.

Note that the Washington Water Code provides for expedited processing of water right applications for certain types of water storage proposals (RCW 90.03.370[1][b]).

In May 2003, the Governor signed Substitute Senate Bill 5575 which amended the Washington Water Code regarding permitting of small irrigation impoundments. That bill declared that reservoir and secondary use permits are not required for lined surface water impoundments, less than 10 acre-feet in volume, used to impound irrigation water under an existing water right and that (1) facilitates efficient use of water or promotes compliance with an approved recovery plan for endangered or threatened species; and (2) does not expand the number of acres irrigated or the annual consumptive water use. The bill also exempts from reservoir permitting those facilities that recapture or reuse return flows from irrigation operations serving a single farm as long as the irrigated acreage does not increase.

Other state laws allow for groundwater storage based upon creating a groundwater management area or sub-area by Ecology, the filing of declarations by a water user claiming to store and withdraw groundwater, and confirmation by Ecology. There are several existing rights to store and withdraw groundwater established under this process.

Dam Safety Permit

A Dam Safety Construction Permit is required from the Department of Ecology's Dam Safety Office before constructing or modifying any dam or controlling works that can store 10 or more acre-feet of water. Ecology also inspects the construction of all dams to reasonably secure safety of life and property.

Other State Permits

Department of Natural Resources (DNR) Forest Practices Permit. A forest practices approval is required of the owner/operator of land and timber before beginning certain forest practices, such as harvesting, road construction, etc. (RCW 76.09 and WAC 222).

Ecology Water Quality Modification. These permits are issued to address turbidity in water during construction, chemical applications in water, or other situations requiring a temporary modification of a water quality standard (RCW 90.48.445 and WAC Chapter 173.201A-110(2)).

1.3.6 DNR Water Types

With regards to evaluating possible sources of excess winter water, and means of storing the excess water, water type as defined by Washington Department of Natural Resources (DNR) is an important consideration. The state interim water typing system (WAC 173-222-031) is in use until the state adopts an updated fish habitat water typing (WAC 173-222-030). A summary of the state interim water typing system is as follows:

- **Type 1 water** means all waters within their ordinary high-water mark and inventoried as "shorelines of the state" (Chapter 90.58 RCW), but not including those waters' associated wetlands.
- **Type 2 water** means segments of waters not classified as Type 1 and having high fish, wildlife, or human use (as specified in WAC 173-222-031).
- **Type 3 water** means segments of waters not classified as Type 1 and having moderate fish, wildlife, or human use (as specified in WAC 173-222-031). Of relevance to this project, snowmelt streams are not designated as Type 3 waters if they discontinue flow by June 1.
- **Type 4 water** means perennial non-fish habitat streams (as specified in WAC 173-222-031). For the purposes of stream typing, Type 4 waters include intermittent dry portions of the perennial channel below the uppermost point of perennial flow.
- **Type 5 water** means segments of waters not classified as Type 1, 2, 3, or 4. These are seasonal, non-fish habitat streams in which surface flow is not present for at least some portion of the year and are not located downstream from any Type 4 stream reach.

WAC 173-222-031 provides additional detail regarding the interim water typing system. On the water type map obtained from DNR (May 2003) for this project, **Type 9 waters** are those that have not been typed. They are typically small streams and are assumed to not be fish-bearing.

In the Upper Little Klickitat Watershed Analysis prepared by Boise Cascade Corporation (Raines et. al. 1999), the existing state water type map was "corrected" for this upper portion of the Little Klickitat subbasin to incorporate the Forest Practices Board's 1996 emergency rule redefining the physical parameters (stream width, gradient, drainage area) used to describe Type 3 waters, and based on 1997 field surveys to document fish presence. From this process, approximately 72 miles of stream were changed from Type 4 or 5 to Type 3 (assumed fish-bearing) using the emergency rule criteria. Of these 72 miles, approximately 43 miles are dry during autumn (e.g., Dry Creek). Review of current water type map for WRIA 30 indicates that DNR has incorporated the "corrected" stream types into their map. The water types for Swale Creek and Little Klickitat subbasins are shown on Figures 5 and 8, respectively.

For the purposes of this screening assessment, it is assumed that Type 1, 2, and 3 streams are fish-bearing, whereas Type 4 and 5 are not. If the Planning Unit chooses to proceed with further evaluation of specific storage projects, additional evaluation of water type, and associated aquatic resource values, would be warranted for specific stream segments considered as sources of excess water or considered for instream benefit from release of stored water. Based on the current hydrologic understanding of the two priority subbasins, limiting sources of excess water to Type 4 and 5 waters may not provide sufficient excess flow volumes to make water storage projects cost effective.

2 April 2003 Field Data Collection

Because few hydrologic data exist for the Swale Creek and Little Klickitat subbasins, a focus of this screening assessment was the collection of some baseline hydrologic data in these subbasins. Field data was collected to gain preliminary understanding of the relative availability of excess water in different streams, and improve understanding of groundwater-stream interactions, in the priority subbasins. For the latter objective, the field effort included observation of surficial geology and spring discharge locations, which was particularly informative in the Swale Canyon (described below).

Stream Gaging. Stream gaging was a primary focus of the April 2003 data collection, with the objective of understanding the relative magnitude of excess flows between different drainages and to document potential gaining or losing reaches of the creeks. The stream gaging provides a single point-in-time measurement of stream discharge that supplements the scant available gaging data from these subbasins. A total of 28 stream discharge point measurements were collected the week of April 21-25, 2003: 3 measurements from Swale Creek and 25 measurements from 11 streams spread across the Little Klickitat subbasin (Table 4).

Flows were measured using the velocity-area method. This method involves measuring the channel cross-section and velocity at multiple stations across the channel. Each channel cross-section was established by stringing a tape measure across the channel perpendicular to the flow direction. Measurements were taken at approximately 4 to 12 stations, depending on the channel width and uniformity, along the cross section. At each station the following measurements were taken:

- Horizontal position (read from the measuring tape);
- Depth to the water surface (measured vertically down from the measuring tape);
- Depth to the channel bottom (measured vertically down from the measuring tape); and
- Average velocity (measured with a current meter at that station).

Average velocity was measured using a Swoffer 3000 current meter with a 2" propeller. The propeller was set at a distance above the channel bottom equal to 60 percent of the total depth.

Flow is calculated by dividing the channel into rectangular sections based on the station data and using the following formula:

$$Q = (w_1 * d_1 * v_1) + (w_2 * d_2 * v_2) + (w_3 * d_3 * v_3) + ... + (w_n d_n v_n)$$

where Q is the total flow in cfs, w is the width of each rectangle in feet, d is the depth of each rectangle in feet, v is the average velocity in feet per second, and n is the number of rectangles.

As a check on the accuracy of the flow measurements, flows were measured immediately above and below the confluence of Dry Creek with its largest tributary (Brimstone Creek), and in Brimstone Creek. If flows are accurately measured, then the downstream

flow should equal the upstream flow plus the tributary flow. The measured flow upstream (Dry-2 location) was 4.7 cfs and the measured Brimstone Creek flow (Dry-1) was 1.9 cfs. Based on these two measurements, the predicted downstream flow would be 6.6 cfs, but the measured flow was 6.4 cfs (Dry-3) indicating a measurement error of 3 percent. The measurement error of 3 percent is relatively low for streamflow measurements, and provides reasonable confidence in the discharge measurements collected for this project.

Water Quality Sampling. In addition to the stream gaging, water samples were collected at selected surface water and spring locations for chemical analysis. The objective of collecting the water quality data are to provide an additional line of evidence (geochemical) to evaluate the relative contribution to instream flows from snowmelt or surface runoff versus groundwater discharge. This information would be most useful by comparing the April 2003 data with data collected during the late summer since the relative contribution of groundwater versus snowmelt should change seasonally, and might be reflected in water quality.

The surface water samples were grab samples collected using a plastic container submerged into the stream, from which the water was poured through a plastic funnel into the laboratory-supplied plastic sample bottles. The sample aliquots for iron and manganese analysis were not filtered in the field and the sample container for these analyses contained nitric acid preservative.

The water samples were submitted to an Ecology-certified analytical laboratory (North Creek Analytical in Bothell, Washington) for analysis of conventional water quality parameters used to assess each water sample's geochemical "signature." Analytes included major cations (calcium, magnesium, sodium, potassium), major anions (bicarbonate, sulfate, chloride), and dissolved iron and manganese. Water hardness is calculated from the calcium and magnesium concentrations. Field parameters - temperature, pH, and electrical conductance - were also measured in the field at each location where stream gaging was performed, whether or not a water sample was also collected for full laboratory analysis. A total of 19 water samples were submitted for laboratory analysis, and water quality field parameters were measured at 34 locations in April 2003 (Table 5).

Given that project funding was authorized at the end of March 2003, the April 2003 data collection was completed toward the end of the spring runoff period. In addition, 2003 had below average snowpack, and meltwater runoff from Simcoe Mountains snowpack peaked earlier than usual. Consequently, local instream flows in April 2003 were lower than the historical average for April. Regardless, the data collected do provide useful information to evaluate potential excess water flows in a relative sense between various stream drainages within the subbasins. More accurate assessment of available excess flows would require installation and year-round continuous monitoring of stream discharge if potential storage projects and candidate streams are identified by the Planning Unit.

The field data collection efforts are described for each subbasin in the next two sections.

2.1 Swale Creek Subbasin

A field reconnaissance of the Swale Creek subbasin was completed on April 1 and 2, 2003. The first day included a reconnaissance of the upper and central subbasin – from the headwater tributaries east of Highway 97, through the Centerville valley, down to Harms Road just west of Warwick. The second day involved a reconnaissance of the entire Swale Canyon, from Harms Road to the creek mouth at Wahkiacus. The reconnaissance effort included visual estimates of stream flows in tributaries, observation of stream channel development, surface geology and structure, and spring discharge. Field observations are recorded on Figure 2 (oversize plate).

On April 21, 2003, stream gaging was performed at three locations on Swale Creek: just upstream from the creek mouth (Swale-1A; river mile [RM] 0.3, just upstream from Horseshoe Bend Road bridge), at Harms Road (Swale-2; RM 12.2), and at Highway 97 (Swale-3; RM 24.2). Measured flows at the three stations were 5.1, 1.0, and 0.6 cfs, respectively. The gaging data from all locations are presented in Table 4. Several small tributaries were observed entering Swale Canyon, with individual flows estimated visually from less than 0.1 cfs to perhaps 1.5 cfs. On Figure 2, the discharge measurement locations are shown as triangles, and the visual qualitative flow estimates are shown as circles. For the qualitative flow estimates, the term "significant flow" ("sig. flow" on Figure 2) indicates flow that likely fell in the range of 0.5 to 1.5 cfs. The term "minor flow" indicates flow that likely fell in the range of 0.1 to 0.5 cfs, and the term "trickle" was used for flows likely less than 0.1 cfs.

In addition, water quality samples were collected from Swale Creek at each of these three gaging locations (temperature, pH, and conductance data are presented on Figure 2). Water quality samples were also collected from two spring locations that had sufficient discrete flow to allow sample collection. Water sample Spr-1-Swale was collected from a small spring emanating from the Wanapum Basalt on the north side of Swale Creek (at RM 9.4). Visual reconnaissance above the spring confirmed it was not fed by higher elevation surface runoff. This spring was the first one observed west of Harms Road that had sufficient flow for water sample collection. The spring area had substantial vegetative growth, including aspen trees, suggesting year-round spring discharge. Further down Swale Canyon, at RM 3.4, water sample Spr-2-Swale was collected from a small spring emanating from the Grande Ronde Basalt on the east side of the canyon. These spring sample locations are shown on Figure 2.

A water quality sample was also collected from the mainstem Klickitat River next to the mouth of Swale Creek (Mainstem-1; Table 5), providing a point of comparison with the water quality data collected throughout the Swale Creek and Little Klickitat subbasins.

The water quality data – laboratory and field parameter – collected from the Swale Creek subbasin are presented in Table 5.

2.2 Little Klickitat Subbasin

A field reconnaissance of the Little Klickitat subbasin was conducted between April 21-25, 2003. During this time, we collected stream/spring discharge and water quality field

parameter measurements at 25 locations, and 13 water quality samples for full laboratory analysis (3 samples of spring discharge and 10 samples from streams).

Stream gaging was performed at the following locations:

- Two locations on Blockhouse Creek (RM 3.9 and 4.3);
- Two locations on Bloodgood Creek (at RM 0.4, and at Bloodgood Springs where the spring discharge enters the culvert under Pine Forest Road);
- Four locations on Bowman Creek (RM 0.5, 3.6, 12.8, and 16.8);
- Two locations on Butler Creek (RM 0.1 and 3.7);
- Two locations on Canyon Creek (RM 5.0 and 8.6);
- One location at RM 2.1 on Devil's Canyon, a tributary joining Mill Creek at RM 11;
- Three locations on Dry Creek (RM 0.7, 1.9, and 2.1) and on a tributary (Brimstone Creek) joining Dry Creek at RM 2.0;
- One location at RM 0.3 on the East Prong Little Klickitat River;
- One location at RM 0.7 of Idlewild Creek;
- Four locations on Mill Creek (RM 4.0, 8.4, 12.7, and 14.5); and
- Two locations on the West Prong Little Klickitat River (RM 0.06 and 4.7).

The data collection locations, with discharge and field parameter measurements, are depicted on Figure 3. The stream gaging data and water quality data are presented in Tables 4 and 5, respectively.

In addition to sampling stream surface water at 10 locations (see Table 5), water quality samples were also collected from Shelton Spring (T6N R14E section 35), Presher Spring (T6N R15E section 34), and Bloodgood Spring (T4N R16E section 8). Note that the USGS topographic map also identifies another Shelton Spring in T5N R14E section 12 – approximately 1.7 miles southeast of the Shelton Spring we sampled.

The water sample from Bloodgood Spring was collected as a grab sample from the eastern of the two vaults within the City of Goldendale's spring collection system. The measured discharge from Bloodgood Spring was 7.8 cfs at the point where the discharge enters a culvert under Pine Forest Road. Bloodgood Spring discharges from the Simcoe Volcanics.

Shelton Spring occurs as diffuse seepage along the banks of a tributary to Canyon Creek, meandering through unconsolidated overburden. Shelton Spring occurs near the western extent of the Simcoe Volcanics but, based on the DNR geologic map (Figure 6), discharges from the Wanapum Basalt in a narrow valley incised down through the younger Simcoe Volcanics.

At Presher Spring, a pair of small-diameter ABS pipes have been installed that direct and aerate the artesian discharge within a fenced area. The discharge was estimated at 50 to 75 gpm (0.1 to 0.2 cfs) at the time of April 2003 observation. Presher Spring discharges from the Simcoe Volcanics.

2.3 Analytical Data Quality Assurance Review

A quality assurance review of the laboratory's analytical data packages was performed to ensure that the data were of suitable quality for their intended use. The samples were delivered to the lab in two sample delivery groups (SDGs) – SDG B3D0085 including four samples collected on April 1 and 2, 2003, and SDG B3D0605 including 15 samples collected between April 21-25, 2003. The laboratory certificates of analysis are included in Appendix A.

The quality assurance review included evaluation of sample custody, holding times, method blank analysis, laboratory control sample (blank spike) and matrix spike/matrix spike duplicate recoveries and precision, and post-digestion spike recoveries. The results of the quality assurance review are as follow:

1. Sample custody and holding times were acceptable.
2. No method blank contamination was detected.
3. Laboratory control sample (LCS) recoveries were within control limits.
4. Matrix spike (MS), matrix spike duplicate (MSD), and post-digestion spike recoveries were outside of control limits for calcium, magnesium, and/or sodium for SDG B3D0085 (4 samples). The lab's QC report noted that corresponding concentrations in the sample (not from this project) used for that batch's spike analysis were very much greater than the spike concentration. In this case, control limits on recoveries are not reliable. Because of this, and the fact that the LCS recoveries, approximating lower concentrations closer to those in project samples, were acceptable, the data for those analytes were not qualified. This is further supported by the MS/MSD results from the other project SDG (B3D0605), for which the spike was done on a project sample and had results within control limits.
5. The relative percent differences (RPDs) for MS/MSD sample pairs were within control limits.

Based on the quality assurance review, the analytical data are determined to be of acceptable quality for their intended use.

3 Water Storage Opportunities for Swale Creek Subbasin

This section outlines, for the Swale Creek subbasin, the current conceptual model for subbasin hydrology, identifying groundwater-surface interactions that may constrain how water can be stored and/or subsequently used; evaluation of where and how much excess water may be available for storage; and application of the four conceptual water storage options (Section 1.3) specifically to this subbasin.

3.1 Hydrologic Conceptual Model

Much of the surface runoff within the Swale Creek subbasin occurs in numerous small tributaries draining the Columbia Hills that flank the southern edge of the subbasin. Based on field observations, lesser runoff occurs in several small tributaries flowing south from the unnamed anticline (ridge) bordering the Swale Creek valley to the north. Within Swale Canyon, there are somewhat fewer tributaries draining High Prairie to the west, but some of these tributaries appear to convey somewhat greater flows than those entering the Swale Valley east of Warwick.

East of Warwick, the Swale Valley is an alluvium-filled basin within an east-west trending synclinal trough of the Wanapum Basalt. Alluvial deposits have filled the central axis of the valley between approximately Highway 97 on the east and Warwick on the west, with depths to bedrock along the valley axis greater than 200 feet near Centerville. Groundwater in this basin occurs within both the alluvial deposits (Alluvial Aquifer) and the underlying Wanapum and Grande Ronde Basalts. West of Warwick, Swale Creek Canyon is incised deeply within Wanapum and Grande Ronde Basalts, with little alluvium except along the lowermost 2 miles. Figure 4 is a geologic map of the Swale Creek subbasin (from Washington DNR; November 2000), showing surficial geologic units and alignments of major geologic folds and faults.

Swale Creek between approximately Highway 97 and Warwick is an expression of the water table in the Alluvial Aquifer. As such, it is ephemeral or of a seasonal nature directly related to the groundwater level in the alluvium. In early spring, groundwater levels in the alluvium are generally high (shallow depth below the ground surface). Localized flooding of the low-lying areas around Swale Creek has reportedly occurred during particularly wet periods in the late winter and early spring. This portion of the creek is generally dry by late spring/early summer and for the balance of the year as groundwater levels in the alluvium decline. Groundwater level data from the 1960s to present indicate the groundwater levels rebound each spring, with no apparent long-term water level declines in that period.

The Warwick Fault, running northwest-southeast through Warwick, is an important structural control on groundwater flow in this subbasin, including the interaction of groundwater with Swale Creek. Based on regional assessment of structural controls (folds and faults) in the basalts, Newcomb (1969) concluded that the Warwick Fault, which

bisects the western portion of Swale Creek valley at Warwick, forms a structural closure to the Swale Creek valley and thus should create an impoundment of groundwater to the east of the fault. Previous USGS interpretations of regional groundwater flow conditions indicate that the Warwick Fault does impound groundwater in the overlying Wanapum Basalt, but there were no specific data to confirm the same for the Grande Ronde Basalt. However, the Yakama Nation recently drilled a 100-foot deep well into the Grande Ronde Basalt near Wahkiacus, just east (upgradient) of the Warwick Fault. The well is flowing artesian, with a flow of 700 gpm and a shut-in pressure of 10 psi. The presence of considerable excess pressure upgradient of the fault suggests that it also impounds groundwater in the Grande Ronde.

The presence of the Warwick fault on the western margin of Swale Creek valley, which impedes westerly groundwater flow within the basalts, together with low summer surface water flows within Swale Creek Canyon (west of Warwick), suggest limited baseflow contribution of groundwater from the basalts to the creek. The April 2003 field reconnaissance of the entire Swale Creek Canyon (prior to start of irrigation pumping in the region) confirmed very low quantities of spring discharge from the basalts. Anecdotal information from a 40-year resident (Mr. Tony Sareson) of the upper Swale Canyon indicates that, as soon as flows off of the Columbia Hills dry up, Swale Creek dries up every year he's lived there, except at Warwick and in scattered pools throughout the canyon.

Based on the collective information, flows in Swale Creek appear to be supported principally by runoff from numerous small tributaries draining the surrounding uplands (e.g., Columbia Hills and High Prairie). Groundwater discharge provides minimal baseflow to Swale Creek.

3.1.1 Water Quality Data

The April 2003 water quality data demonstrate that Swale Creek surface water has the highest dissolved solids (lowest water quality) of any groundwater or surface water sample collected in the Swale Creek and Little Klickitat subbasins during this study (see Table 5). The three Swale Creek surface water samples (at Highway 97, at Harms Road, and near the mouth) had the three highest electrical conductance (EC) measurements (160 to 270 µS/cm), which is a direct measure of total dissolved solids. They also had the three highest water hardnesses (measure of calcium and magnesium concentrations), and the three highest concentrations of potassium, sodium, bicarbonate, and chloride. Sulfate detected at the upper two Swale Creek locations were also higher than that detected in the other samples from this study. Stream temperatures measured on April 21, 2003, were 11°C at Highway 97 and 16°C near the mouth. On April 2, 2003, stream temperature at Harms Road was 10°C.

Water quality improved consistently with distance downstream - from Highway 97 to Harms Road to the mouth (Table 5). The Swale Creek water quality data may reflect higher dissolved solids in the Alluvial Aquifer; however, the highest concentrations occur at the Highway 97 sampling location, which is near the upgradient edge of that aquifer. The lower dissolved solids in the sample collected near the creek mouth indicate that water entering Swale Canyon from surface runoff and minor groundwater discharge is of better quality than water in the upper watershed.

The groundwater quality data from the two spring samples (one each from Wanapum and Grande Ronde Basalt) are similar, with the main difference being higher iron in the sample from the Wanapum (1.5 mg/L) than from the Grande Ronde (0.16 mg/L). The spring samples had lower conductance (80 to 100 µS/cm) than observed in Wanapum wells within the Swale Valley. This may be an indication that groundwater in the basalts west of Warwick has shorter residence time than groundwater in the basalts east of the Warwick Fault.

Despite differences in concentrations, all of the water samples from this subbasin are classified as calcium bicarbonate water types, which is the most common for freshwaters.

The April 2003 sampling data indicate that, for those constituents analyzed, Swale Creek and the springs discharging to it generally have acceptable water quality relative to both Washington state water quality criteria (WAC 173-201A) and drinking water standards. The exception is iron. Iron was detected in samples from the Wanapum Basalt spring and the upper two Swale Creek locations at concentrations above the 0.3 mg/L secondary drinking water standard, which is based on aesthetic (color, taste) rather than health concerns. Note that nitrate has been measured above its drinking water standard in the Alluvial Aquifer at some locations in Swale Valley; this is currently being investigated in greater detail under a separate water quality grant from Ecology.

3.1.2 Existing Water Rights

Table 6 presents the recorded cumulative groundwater and surface water rights and cumulative water claims by water source in the Swale Creek subbasin. This information could be considered in assessment of water storage projects. In particular, using stored water to replace existing water rights for late-season surface water diversion is a potential option. In this case, it may be possible to meet existing water rights for out-of-stream use of surface water, while achieving instream benefit by leaving water in the stream late season. However, as Table 6 indicates, there are very few water rights for surface water diversion in this subbasin (27 acre-feet/year surface water vs. 11,600 acre-feet/year groundwater).

Table 6 - Recorded Water Rights and Claims by Source, Swale Creek

	Cumulative Instantaneous in cfs	Cumulative Annual in AFY
Groundwater Certificates+Permits		
WELL	41	11,632
Totals:	*41*	*11,632*
Surface Water Certificates+Permits		
SWALE CREEK	0.01	11
UNNAMED POND	0.007	1.0
UNNAMED SPRING	0.1	4.5
UNNAMED STREAM	0.06	10
Totals:	*0.2*	*27*
Claims		
#1 SPRING	0.0	1.0
#2 SPRING	0.0	0.5
#3 POND	0.0	1.7
#4 POND	0.0	1.7
SWALE CREEK	0.0	3.1
UNNAMED CREEK	0.0	6.4
UNNAMED SPRING	0.0	0.9
Totals:	*0.0*	*15*

3.2 Excess Water Availability

A necessary step in evaluating water storage options is examining the distribution, timing, and magnitude of streamflows within a subbasin. By understanding where runoff is occurring, when runoff occurs, and how much occurs, we can begin to develop storage strategies appropriate for the subbasin.

3.2.1 Available Streamflow Data

Limited streamflow data are available for the Swale Creek subbasin. There are no continuously recording stream gages located in the Swale Creek subbasin, but some point flow measurements and peak flows estimates are available. Point flow measurements have been collected by several parties at different locations in Swale Creek:

- Yakama Nation Fisheries - periodically measures flow in the canyon near the Horseshoe Bend Road bridge (at the Swale-1A location [RM 0.3]; Figure 2);
- Aspect Consulting - April 21, 2002 flows at RM 0.3, 12.2, and 24.2; and,
- Central Klickitat Conservation District data – periodic point measurements.

Peak flows have been estimated using regional regression equations (Inter-fluve 2002). Inter-fluve's analysis indicated that the 2-year peak flow would be around 900 to 950 cfs and the 100-year could be as much as 6,250 cfs.

Although a useful start for identifying the runoff pattern, these data are not comprehensive enough to characterize average flows or assess the potential average volume available for storage. Alternative approaches for estimating flows include using monthly unit runoff characteristics (flow per unit area) from an adjacent basin, or performing a water balance analysis.

The WRIA 30 Level 1 Assessment (WPN 2003) estimated monthly stream flow for several ungaged subbasins using monthly unit runoff characteristics from other gaged subbasins. However, that assessment concluded that Swale Creek was significantly different from other nearby basins, and thus it would be inappropriate to estimate flows based on gage data from adjacent basins.

Because of the lack of streamflow data, and the difference between Swale Creek and adjacent subbasins, the water balance approach is left as the best approach for estimating discharge.

3.2.2 Discharge Estimates for Swale Creek Catchments

The Swale Creek drainage network is comprised of the mainstem of Swale Creek and numerous small unnamed tributaries draining the surrounding area. Estimating flows for the individual tributary catchments is important to understand the potential locations for storage projects in relation to possible volumes of excess winter water.

Using GIS, 78 smaller catchments were delineated for the Swale Creek tributaries (Figure 5) based on a digital elevation map of the topography. Not all of the catchments depicted have streams or other drainage channels (e.g., UN-08); these catchments would contribute surface flow directly to Swale Creek. None of the tributaries have defined names, therefore all are unnamed (labeled as UN-#). Table 7 provides the areas and top elevations of the delineated catchments within this subbasin.

Flows from each catchment were estimated using a water balance approach based on climatic data and groundwater recharge estimates from Bauer and Vaccaro (1990). The water balance approach estimates discharge according to the following formula:

Discharge = Precipitation - Evapotranspiration - Recharge.

The long-term precipitation record closest to the Swale Creek subbasin is Goldendale (453222) with precipitation readings from 1931 to present. The mean annual precipitation at Goldendale is 17.63 inches, with a seasonal peak in December and January of over 3 inches per month.

Evapotranspiration (ET) data are available from Yakima WSO Airport for 1946 through 2000. The mean annual ET, after application of a pan coefficient of 0.75, is 35.4 inches, which is well in excess of the annual precipitation. ET will only occur to the extent that water is available. Thus, from a runoff perspective (i.e., ignoring irrigation, and shallow groundwater) ET cannot exceed precipitation. ET data are also not available for the

months of October through March, because pan evaporation measurements are not taken during the winter months. We assumed ET to be negligible during this period.

As discussed in Section 5.2 of the Level 1 Assessment (WPN 2003), groundwater recharge was estimated by Bauer and Vaccaro (1990) using a deep percolation model for the entire Columbia Plateau regional aquifer system. Recharge estimates were presented as ranges. For the Swale Creek subbasin, recharge estimates ranged from 1.0 - 2.0 inches in the Columbia Hills east of Highway 97 to 5 - 10 inches in the High Prairie area. To calculate discharge, we assigned a recharge value equal to the middle of the range (e.g., 7.5 inches was used for the 5 - 10 inch range) to each catchment.

The resulting discharge estimates for winter/spring peak flows (assumed December through April) for each of the 78 catchments are shown in Table 8. The water balance predicts an average discharge from Swale Creek of 137 cfs for December through April. This estimate is based on few actual data, and may overestimate or underestimate flows; however, it provides an initial starting point for evaluating storage options. The five catchments with the highest discharge are (in order) UN-77, -12, -75, -78, and -16 with average December-April discharges ranging from 5 to 11 cfs. These catchments are located in the eastern half of the drainage basin. Thirty of the catchments have average December-April discharge greater than 2 cfs.

It is important to recognize that the flows in Table 8 represent total discharge for the winter/spring peak flow period, not the quantity of water available for storage. It is assumed that only some percentage (to be determined in future evaluation of specific projects) of the total winter flows would be diverted or detained for storage.

The December through April discharge volume in each catchment ranged from almost nothing to 3,330 acre feet (UN-77) with most individual catchments yielding between 250 and 1,000 acre feet. Only a fraction of this volume would potentially be available for storage, but given the lack of data in Swale Creek it is inappropriate to estimate the available fraction without further study. The discharge values in Table 8 are also useful as an upper bound for determining the potential size of storage projects.

3.3 Prospective Options for Water Storage

This section evaluates application of the four conceptual water storage opportunities to the Swale Creek subbasin, based on the available information.

3.3.1 Enhanced Recharge in Swale Creek Subbasin

Enhanced groundwater recharge in the Swale Creek subbasin upstream (east) of Warwick is not feasible because the Alluvial Aquifer's water table is essentially at ground surface during the winter months when excess surface water would be available for subsurface storage. During most years, by the time the water table declines in late spring, creating potential storage capacity in the Alluvial Aquifer, there is little, if any, excess surface water left to store. In other words, the shallow aquifer is already full at the time you would want to store additional water.

Excess water could be used to recharge the deeper Basalt Aquifer via deep wells, including pumping into confined aquifer units under pressure. However, the Warwick

Fault greatly limits hydraulic connection between Swale Creek and the basalt aquifers upgradient of Warwick. There would thus be negligible chance for this extra recharge to augment Swale Creek flows through natural groundwater discharge, and negligible benefit achieved from such a project. Again, this option does not include active recovery (pumpage) of the recharged water.

West of Warwick, alluvium is mapped along the bottom 2 miles of Swale Canyon (Figure 4). However, given the overlay of topography, the mapped width of the alluvium along this bottom reach appears to be overestimated. This alluvium unit is likely thin across most of its length, and its unsaturated portion represents small potential storage capacity during winter months. Even if there is some storage capacity there, it could only provide instream benefit near the mouth of Swale Creek.

Therefore, actively enhancing recharge with the intent of augmenting summer low flows in Swale Creek through enhanced groundwater discharge is not considered practical.

3.3.2 ASR in Swale Creek Subbasin

Aquifer storage and recovery (ASR) represents a potential water storage opportunity for this subbasin, assuming sufficient excess winter water is available for the intended uses and to make it cost effective. As discussed in Section 1.3.2, ASR could potentially provide water for any out-of-stream use (municipal supply, irrigation, etc.). It could be used to augment instream flows in Swale Creek, but likely only if released downstream of Warwick (via active pumping and conveyance). Because the stored water could be kept at low temperature underground, it has advantages over surface storage for augmenting instream flows, if that is a defined need for this subbasin. Swale Creek downstream of Warwick reportedly contains fair to good steelhead and coho salmon spawning and rearing habitat (Sharp et. al. 2000; WPN 2003).

Geographic Areas to Consider for ASR

ASR using the Alluvial Aquifer, between Highway 97 and Warwick, is not feasible for the same reason enhanced groundwater recharge is not feasible there (see Section 3.3.1). However, ASR could be feasible in this area using deep well(s) completed in the underlying Wanapum or Grande Ronde Basalt Aquifers. Use of the stored water to augment Swale Creek instream flows east of Warwick in the summer would likely have minimal benefit because much of the water is expected to infiltrate into the alluvium when the water table is lower. However, stored water in this area could be used for irrigation supply, or could be piped and released west of Warwick. As discussed above, long-term groundwater level trends indicate groundwater levels in the Basalt Aquifer are stable over the past several decades, indicating natural recharge is adequately replenishing groundwater discharged by pumping, over the long term. Therefore, use of water storage to replenish the Basalt Aquifers may not be warranted based on existing uses, but could be warranted if expanded irrigation needs are identified in this area.

Instream flows within Swale Canyon could be augmented by releasing stored water west of Warwick. It is questionable whether ASR could be used for multiple purposes in this area. As presented in Section 6 of the Level 1 Assessment (WPN 2003), there are very few recorded water rights, but many water claims, in the Swale Creek subbasin generally west of Warwick. None of these are for large water uses so, currently, there are not major

out-of-stream water uses identified in this area. If new out-of-stream uses were identified in this area, ASR could potentially be used to help meet these needs along with augmenting Swale Creek flows.

Within Swale Canyon, basalts occur from ground surface to great depth. The Wanapum Basalt crops out along Swale Creek west of Warwick approximately to the creek's sharp bend to the north; Grande Ronde Basalt crops out along the creek downstream of there (see geologic map on Figure 4). Therefore, ASR using the Grande Ronde Basalt could be an option for the Swale Canyon area, but the ASR well(s) would need to be completed within the canyon – presumably upon the abandoned railroad grade.

Based on the available water quality data, Swale Creek water has higher hardness and dissolved solids than that in the underlying basalts that would be considered as storage aquifers. Consequently, the source water to be stored may require water quality treatment to avoid groundwater quality degradation of the Basalt Aquifer.

3.3.3 On-Channel Dam in Swale Creek Subbasin

On-channel impoundment of the ephemeral tributaries to Swale Creek is a possible option for storing water in this subbasin. DNR designates Swale Creek between the mouth and Warwick as Type 1, and the tributaries feeding that reach as Type 4 or 5. East of Warwick, most of Swale Creek and its tributaries are not typed by DNR (Type 9), except for Type 4 or 5 segments the northeastern corner of the subbasin (Figure 5). Because Swale Creek below Warwick is a Type 1 stream, constructing a dam across it is not considered as an option in this screening assessment. However, damming any of the tributaries to Swale Creek, above or below Warwick, should not be prohibited based solely on stream type.

As discussed for other options above, damming tributaries east of Warwick would have minimal benefit to late-season instream flows because the released water would largely infiltrate into the alluvium.

The intent of storing water in dammed tributaries west of Warwick could be late-season release to provide some flow increases downstream in Swale Creek. However, it is likely that, given the relatively small volumes of water available from any one tributary, the temperature of the impounded water could exceed the temperature water quality standard by the time of its desired release. Potentially, this water might also be pumped to help meet small out-of-stream water demands in High Prairie or surrounding areas.

As noted in Section 3.2, few individual tributaries, east or west of Warwick, are capable of producing a significant volume of water (>1,000 acre feet). Thus, damming multiple tributaries may likely be required to produce a volume of water that might warrant investment in such a project. We expect that the cost to design, permit, and construct a dam on any one of those tributaries would likely outweigh the benefit achieved from that volume of storage. Because the expected cost would be disproportionate to the expected benefit for any single tributary considered, it is expected to also be disproportionate for any combination of tributaries.

3.3.4 Off-Channel Impoundment in Swale Creek Subbasin

As discussed above for the on-channel dam option, each individual tributary to Swale Creek provides relatively small volumes of excess water. However, the off-channel options may be more economically viable than on-channel. It should be less expensive to construct diversion structures/piping from multiple tributaries, all discharging to a common off-channel impoundment, than constructing multiple dams in those same tributaries.

As stated above, most of Swale Creek and its tributaries east of Warwick are untyped based on the water type map provided by DNR. Because Swale Creek east of Warwick represents poor aquatic habitat, diversion of excess winter flows from this portion of the creek into off-channel storage may be able to be permitted, particularly if a net environmental benefit could be demonstrated. This would require more detailed analysis.

Assuming a sufficient volume of excess winter water were available, off-channel storage in this subbasin likely could only be accomplished east of Warwick. West of Warwick, there is likely insufficient room along the creek channel to accommodate an off-channel impoundment of any significance. An off-channel impoundment in the Swale Valley east of Warwick would likely need to be lined to avoid large seepage losses once the Alluvial Aquifer water table drops by early summer each year. There is negligible shade in this area, and water stored in a lined basin during the winter would be expected to have high temperature by summer. However, this warm water may be acceptable for stock watering, small-scale irrigation, or other out-of-stream uses in Swale Valley. As discussed in Section 1.3.4, stored water can be reintroduced back into the stream channel via subsurface means, thus providing cooling.

One potential option for off-channel water storage in this subbasin would be construction of wetlands. Reportedly, there is historical information indicating that wetlands once occupied the Swale Creek valley near Warwick. The Swale Creek channel near Warwick and upstream of it is broad and marshy, suggesting wetlands could be constructed if the appropriate wetland hydrology (water table within 18 inches of ground surface) could be maintained year-round. Constructed wetlands are commonly used across the country for stormwater and wastewater treatment on various scales. Wetlands rely on water inflow and outflow, with the difference of inflow – outflow representing the change in water storage within it. Such an option may require impoundment of water in a constructed basin and gradual release of that water to provide continuous inflow to the wetlands.

Water likely could not be recovered from wetlands as it could be from constructed basins or ponds. Wetlands can, however, provide improvements to water quality, flood control, and off-channel habitat, and these may be considered as benefits of water stored in the wetlands. Reportedly, constructed wetlands in the Yakima River watershed are being used for recreational purposes, in which people pay to access the wetlands property for waterfowl hunting. If stored water were used to maintain the wetlands used for such purposes, recreation could represent an additional beneficial use of that water. Construction of wetlands, like other off-channel options, would likely require acquisition of considerable land area. Because of the generally flat topography across Swale Valley, potential wetlands considered in this area would need to be designed and constructed in a manner to not create water-logged soils on adjacent agricultural properties.

4 Water Storage Opportunities for Little Klickitat Subbasin

This section outlines, for the Little Klickitat subbasin, the current conceptual model for subbasin hydrology; evaluation of where and how much excess water may be available for storage; and application of the four conceptual water storage options (Section 1.3) specifically to this subbasin.

4.1 Hydrologic Conceptual Model

The Little Klickitat subbasin has markedly different hydrology from the Swale Creek subbasin because of the Simcoe Mountains, which typically accumulate significant snowpack at high elevation. Release of snowmelt water during relatively warm winter storms dominates early-season flows in the Little Klickitat subbasin.

Another significant difference is the presence of the Simcoe Volcanics that form the Simcoe Mountains. The Simcoe Volcanics have many flows with a coarse, open texture that permits rapid recharge and good vertical and lateral movement of water. Because of the high permeability of some zones in the Simcoe Volcanics, they can provide large quantities of groundwater. The majority of the documented springs in this subbasin discharge from the Simcoe Volcanics, often feeding the numerous tributary streams to the Little Klickitat River. Water quality is typically excellent in the Simcoe Volcanics because snowmelt provides a large proportion of their recharge and the groundwater residence time can be shorter (less mineralization) than the deeper Wanapum and Grande Ronde Basalts. Figure 6 provides the geologic map for the Little Klickitat subbasin.

The Wanapum Basalt crops out across the lower elevations of the Little Klickitat subbasin. Wanapum Basalt is the bedrock underlying the Little Klickitat River around and downstream from Goldendale. Although fewer springs are mapped discharging from the Wanapum than from the Simcoes, the Wanapum is in hydraulic connection with the Little Klickitat River downstream from Goldendale. The Wanapum also underlies the northeast portion of this subbasin, where the Simcoe Volcanics are absent. The drainages for Idlewild, East Prong, Butler, and the lower reaches of West Prong are all underlain by Wanapum Basalt (Figure 6).

The Grande Ronde Basalt underlies the entire subbasin at depth, but crops out at the surface only in isolated locations. Notably, the Little Klickitat River incises through it for a short distance upstream from its mouth (Figure 6).

Based on the DNR geologic map, several accumulations of alluvium occur within this subbasin, although their individual lateral and vertical extents are considerably less than the alluvium filling Swale Valley east of Warwick. Larger areas of alluvium in the Little Klickitat subbasin occur along the following drainages (Figure 6):

- Little Klickitat River east of Goldendale (near confluences with Cozy Nook and Jenkins Creeks) and west of Goldendale;
- East Prong Little Klickitat River upstream of both the Dry Creek and Idlewild Creek confluences;

- Unnamed tributary to East Prong Little Klickitat, paralleling Box Canyon Road (immediately northeast of T5 – R17E label on Figure 6);
- Dry Creek drainage just upstream of its confluence with the Little Klickitat River;
- Butler Creek upstream from its confluence with Highland Creek; and
- Canyon Creek drainage where it flattens upstream of the deeply incised bedrock canyon (middle of T5 R14E).

The alluvium occurring along these streams is in direct hydraulic connection with the stream. For example, Dry Creek loses enough water to the alluvium that it dries up every year, upstream of it confluence. In 2003, Dry Creek was reportedly dry at Highway 97 by the end of May.

4.1.1 Water Quality Data

Based on the April 2003 data, water quality across the Little Klickitat subbasin, from both streams and springs, is more uniform than that observed in the Swale Creek subbasin (Table 5). This is due to the fact that snowmelt supplies the April stream flows and recharges the Simcoe Volcanics from which two of the three springs sampled discharge. All of the waters are calcium bicarbonate water types.

For the streams sampled, EC (measure of total dissolved solids) was generally below 100 µS/cm and hardness below 40 mg/L. The exceptions were Blockhouse and Bloodgood Creeks, both of which originate at lower elevations, and had slightly higher measurements (EC of 100 to 150 µS/cm and hardness of 48 to 65 mg/L).

Stream temperatures collected the week of April 21-25, 2003, ranged from lows of 5.0 and 5.5°C in Devils Canyon and Butler Creek, respectively, to highs of 13°C in both Blockhouse and Bloodgood Creeks.

The two springs discharging from the Simcoe Volcanics – Presher and Bloodgood – had very similar water quality except that Bloodgood was slightly warmer (11°C). Shelton Springs, discharging from the Wanapum Basalt, has lower EC and hardness (50 µS/cm and 30 mg/L, respectively) than the two Simcoe Volcanic springs but has dramatically higher iron (6.6 mg/L). The elevated iron is consistent with the Wanapum Basalt spring sample collected from Swale Creek subbasin (Spr-2-Swale).

4.1.2 Existing Water Rights

Table 9 presents the recorded cumulative groundwater and surface water rights and cumulative water claims by water source in the Little Klickitat subbasin. This information could be considered in an assessment of water storage projects. In particular, using stored water to replace existing water rights for late-season surface water diversion is a potential option. In this case, it may be possible to meet existing water rights for out-of-stream use of surface water, while achieving instream benefit by leaving water in the stream.

Table 9 - Recorded Water Rights and Claims by Source, Little Klickitat

	Cumulative Instantaneous in cfs	Cumulative Annual in AFY
Groundwater Certificates+Permits		
INFILTRATION TREN	0.8	269
SUMP	0.4	68
WELL	68	18,572
Totals:	*69*	*18,910*
Surface Water Certificates+Permits		
BLOCKHOUSE CREEK	14	1601
BLOODGOOD SPRS	2	1338
BOWMAN CREEK	4.3	954
CARROLLS CREEK	1.8	311
COZY NOOK CREEK	3.1	486
DEVILS CANYON CRE	2.2	529
DRY CREEK	0.3	75
EMERSON SPRS	0.4	1363
KLICKITAT RIVER	0.2	32
LITTLE KLICKITAT	8.2	2074
MCCLINTOCK SPRING	0.01	2.0
MILL CREEK	6.3	1250
ROCKWELL SPR	0.5	371
SMITH-WARREN CREE	0.1	11
SPRING BRANCH	0.2	0.0
SPRING CREEK	18	2382
STUMP CREEK	2.5	400
UNN (MCCLINTOCK)	0.4	150
UNNAMED POND	0.02	25
UNNAMED SOURCE	0.0	10
UNNAMED SPRING	6.4	1040
UNNAMED STREAM	4.0	732
Totals:	*75*	*15,136*
Claims		
BOWMAN CREEK	0.0	1528
DEVILS CANYON CRE	0.0	1.3
DRY CREEK	0.0	1.3
IDLEWILD CREEK	0.0	1.3
MIDDLE PRONG CREE	0.0	1.3
MILL CREEK	0.0	1.3
UNNAMED POND	0.0	1.1
UNNAMED SPRING	0.0	0.6
WEST PRONG CREEK	0.0	1.3
Totals:	*0*	*1537*

4.2 Excess Water Availability

This section evaluates the magnitude, timing, and distribution of streamflows within the Little Klickitat subbasin as an initial step in evaluating the quantity of water potentially available for storage. This analysis used a different approach for estimating flows than what was done for Swale Creek, because more streamflow data are available for this subbasin.

4.2.1 Available Streamflow Data

Long-term daily streamflow data are available from three USGS gages in the Little Klickitat subbasin (Table 10). The two Little Klickitat gages have a common period of record from 1957 through 1970. Flow data from Mill Creek is only available from 1964 through 1972. These periods occur during a Cool/Wet period of the Pacific Decadal Oscillation (PDO). Thus, results from this analysis likely overestimate the long-term average streamflow and streamflow during Warm/Dry periods (WPN 2003). None of these gages are currently active.

Table 10 - USGS Stream Gages in Little Klickitat Subbasin

Gage Name	Gage No.	Drainage Area in sq. miles	Period of record	Years of record
Little Klickitat R Nr Wahkiacus	14112500	280	Dec 44 - Sep 48 Oct 50 - Oct 81	36
Little Klickitat R Nr Goldendale	14112000	83.5	Oct 10 - Jun 12 Oct 46 - Sep 51 Oct 57 -Sep 70	20
Mill Creek Nr Blockhouse	14112400	26.9	Aug 64 - Sep 72	8

Average monthly flows and average flow per unit area from these three gages are shown on Figure 7. The data indicated some differences in hydrologic response throughout the Little Klickitat subbasin. The Little Klickitat Nr Goldendale gage represents flow from the eastern, more mountainous, portion of the subbasin. Mill Creek is a single drainage originating at higher elevation in the Simcoe Mountains, then descending to flatter forest and agricultural lands. Finally, the Little Klickitat R Nr Wahkiacus gage is located near the mouth of the Little Klickitat and is a good representation of the total discharge from the subbasin. Several observations about hydrologic response in these gages are instructive for understanding streamflow distribution in the subbasin:

- The highest average flows in the Little Klickitat occur in February as a result of snowmelt. Precipitation is typically highest in November through January. The higher flows of the winter precipitation and subsequent snowmelt period appear to last from December through May.
- The drainages contributing flow to the Little Klickitat Nr Goldendale have a greater (in terms of flow per unit area) hydrologic response than either Mill Creek or the Wahkiacus gage.
- Peak flows occur later, and are more subdued in Mill Creek than in the Little Klickitat gages.

- Mill Creek has the highest baseflow per unit area during summer months as a result of spring flow contributions.
- The total flow at the Wahkiacus gage is greater than the sum of the Goldendale and Mill Creek gages as there is a significant portion of the subbasin (primarily in the west) ungaged. This remaining portion of the basin likely has a hydrologic response lower than the Wahkiacus gage through winter, and slightly higher than the gage during summer. This conclusion agrees with the observation that the ungaged portion of the basin is generally lower elevation, with multiple springs contributing flow year round.

The WRIA 30 Level 1 Assessment (WPN 2003) evaluated the Wahkiacus gage data to look for trends over time (e.g., an increase or decline in runoff). The Level 1 Assessment identified no significant trends in mean annual streamflow, but did identify a statistically significant trend of declining annual low flows at this gage.

Four other stream gages have been operated in the Little Klickitat subbasin. Gages on Spring Creek and Butler Creek recorded daily streamflow measurements from 1964 to 1968. Peak annual flows were recorded on the West Prong (1961-1975) and an unnamed tributary to the Little Klickitat (1960-1988). Because these data represent peak flows or were only collected for short periods, they are not as useful for estimating average streamflow.

Point flow measurements are also available from two sources:

- Aspect Consulting - April 21, 2003, flows at locations throughout the subbasin (Figure 3); and,
- Central Klickitat Conservation District.

The point flow measurements are instructive for understanding the distribution of flow throughout the drainage basin. The April 21, 2003, measurements represent flows near the end of the snowmelt period. Significant flow was observed in most drainages, but many of the smaller tributaries were dry. Flows were highest in the drainages with significant area at higher elevations. Point measurements collected throughout the basin during several other times of the year (particularly in late summer and November - December) would be useful for further defining the distribution of flows.

4.2.2 Discharge Estimates for Little Klickitat Drainages

Discharge estimates for each of the major drainages in the Little Klickitat subbasin (Figure 8) were created using the unit area runoff characteristics of the three long-term gage records in the basin. Table 7 provides the areas and top elevations of the delineated drainages within this subbasin. Generally, each drainage was assigned the existing gage thought to be most representative of the hydrologic response of the drainage. The Goldendale gage was assigned to each of the drainages upstream of Goldendale. The Mill Creek gage was assigned to the longer drainage basins in the western portion of the subbasin (Canyon, Bowman, and Mill). The Wahkiacus gage was assigned to the remainder.

Discharge estimates were calculated by multiplying the drainage area by the unit runoff of the representative gage. Two adjustments were made based on the April 2003 observations and other anecdotal information:

- The unit runoff for Idlewild and Dry Creek was set to 0 for the summer as these drainages are known to frequently be dry at that time.
- The unit runoff for the smaller, lower elevation drainages (e.g., the unnamed drainages, and drainages south of the Little Klickitat) was scaled back by 15 percent so that the total runoff from the subbasin matched that observed at the Wahkiacus gage.

The resulting discharge estimates are shown in Table 11. As with the Swale Creek estimates, these discharge results are initial estimates and are based on limited information. The actual discharge from any particular drainage could be higher or lower than indicated. Most likely flows from the higher elevation, bedrock drainages (e.g., Idlewild, Butler) are underestimated, and flows from the lower elevation drainages (e.g., Remaining Klickitat, Blockhouse) are overestimated. Although included in Table 11, the Remaining Klickitat drainage is not as relevant for evaluating storage options as the other drainages, because it covers a wide area that collects flow through many small tributaries.

The December through May estimates are more useful than the annual estimates for evaluating the quantity of water potentially available for storage. Also note that roughly 80 to 95 percent of the annual discharge occurs between December and May.

The drainages with the highest estimated average discharge are Bowman and Mill at over 10,000 acre feet per year, followed by Canyon at 8,800 acre feet (Table 11). The next tier of drainage basins are predominately located in the eastern portion of the subbasin with the East and West Prongs, Butler and Dry Creek each yielding between 3,900 and 5,600 acre feet per year. Finally, there is a tier of smaller drainages (area less than 6 square miles) that yield less than 2,000 acre feet.

4.3 Prospective Options for Water Storage

This section evaluates application of four conceptual water storage opportunities to the Little Klickitat subbasin, based on the available information.

4.3.1 Enhanced Recharge in Little Klickitat Subbasin

As described above, there are several areas where sizeable deposits of alluvium occur along stream channels within this subbasin, with the largest areas occurring along the mainstem Little Klickitat River. Enhanced groundwater recharge may be a viable option within this subbasin if sufficient thicknesses of unsaturated alluvium can be located to provide a meaningful volume for storage.

As discussed in Section 1.3.1, there are many water rights in this subbasin for collection of spring discharge (Simcoe Volcanics) and use of that water for various out-of-stream uses. If summer discharge from such springs is low, it may be possible to increase winter recharge to the bedrock aquifer supplying the springs, and use extra discharge in summer.

Regardless of using alluvium or basalt as the storage aquifer, locations for such artificial recharge would also need to be positioned so that discharge of the added water occurs at the appropriate location and time to provide the intended benefit.

4.3.2 ASR in Little Klickitat Subbasin

Aquifer storage and recovery (ASR) is an option to provide additional water for both instream and out-of-stream uses, potentially including municipal supply, in the Little Klickitat subbasin. Excess winter flows would be diverted from higher elevation streams and injected to a local aquifer using a well(s). During the summer, stored water would be withdrawn from the same well(s).

Two potential ASR concepts are identified here – one specific and one general:

1. ASR to improve source capacity and reliability for the largest public water system in WRIA 30 (City of Goldendale) and augment summer low flows; and
2. ASR within the Simcoe Volcanics, at locations corresponding to subsequently defined water needs.

These two general concepts are discussed below.

City of Goldendale ASR

The first ASR option would be subsurface storage of excess winter water from the City of Goldendale's Simcoe Springs supply. Currently, winter excess from the City's Simcoe Springs source overflows into the West Prong Little Klickitat River in the Simcoe Mountains. In addition, overflow from the lower reservoir is metered and discharged to a ditch that drains to the Little Klickitat River at Goldendale. Rather than overflowing to the river, the excess water could be stored by the City in the Wanapum Basalt via a newly constructed well within the City's water service area. The stored water would be subsequently recovered in the summer to help the City meet its peak municipal demand. A portion of this water could also be used to augment instream low flows in the Little Klickitat River. Storing this excess water underground until summer, instead of losing it from the watershed during the winter, potentially provides both instream and out-of-stream benefits that may justify the cost of such a project.

We expect that the source water quality (Simcoe Springs) would be better than water quality in the Wanapum Basalt storage aquifer. As such, a portion of the recharged water may end up with poorer water quality as a result of mixing with the ambient groundwater. This would be a consideration in determining the volume of recoverable water under this option, and thus its overall cost effectiveness.

ASR Using Simcoe Volcanics

The second ASR option is less specific and involves diverting excess winter water from higher elevation stream reaches and injecting it for storage within transmissive portions of the Simcoe Volcanics aquifer system. The City of Goldendale's recently completed chlorination station well (T5N R16E section 21) demonstrated that the Simcoe Volcanics can represent a highly productive aquifer. However, the viability of using the Simcoe Volcanics for ASR is untested.

In this option, excess winter water from one or more streams would be piped, under gravity or pumped, to the ASR well site. The stored water would later be withdrawn from the well and then pumped or flow by gravity to the location(s) of use for out-of-stream and/or instream uses. Because the stored water could be kept at low temperature underground, it has advantages over surface storage for augmenting instream flows, if that is a defined need for this subbasin. As discussed in Section 4.2, winter excess water could potentially be diverted from any one of several drainages in this subbasin, depending on where the need for the water occurred. We expect that diverting some percentage of winter peak flows for storage could be permitted even for streams assumed to be fish-bearing (water types 1-3); however, the specifics of timing of fish presence and habitat needs relative to the diversion timing would need to be evaluated as part of a specific project proposal.

4.3.3 On-Channel Impoundment in Little Klickitat Subbasin

On-channel impoundment of the higher elevation reaches of streams draining the Simcoe Mountains is a prospective opportunity that could provide potential benefits to both instream and out-of-stream uses.

If storage occurred in the upper reaches of the watershed, this option could potentially provide late-season instream benefit to the Little Klickitat River through increased flow and decreased temperature, along with additional flow available for diversion to out-of-stream uses. Given that location of an on-channel dam is effectively constrained to steep bedrock channels, the flatter, lower-elevation stream reaches of the subbasin (e.g., Bloodgood, Blockhouse, Spring Creeks) are not considered viable geographic areas for this option in this screening assessment.

Geographic areas given preliminary consideration as possible options for the on-channel dam option are described below.

Dry Creek and/or Idlewild Creek

Dry Creek and Idlewild Creek are headwater tributaries of the Little Klickitat River (Figure 7). Increased summer flows released from impoundments on these headwater streams have the potential advantage of benefiting most of the downstream extent of the Little Klickitat River. Specifically, this option potentially could help lower summer stream temperature in temperature-impaired (303d-listed) reaches of the East Prong Little Klickitat, downstream of Dry Creek and/or Idlewild Creek confluences. Note that the 303d listing PU81CT for temperature in East Prong Little Klickitat (see Table 1) is actually Idlewild Creek just above its confluence with East Prong.

Butler Creek could also be an option to consider for on-channel storage. However, Butler Creek is known to convey higher flows perennially and, as such, may have greater habitat value than Dry or Idlewild Creeks. Therefore, we expect there would be less net instream benefit achieved through on-channel storage on Butler Creek than on either Dry or Idlewild Creeks. On-channel storage on Butler Creek is not considered further in this screening assessment.

Dry Creek. Dry Creek is designated as a Type 3 water, and rainbow trout have been observed there (Raines et. al. 1999). It is ephemeral, losing flow into the extensive alluvium along its lower 2+ miles. Generally upstream from the alluvium, Dry Creek is

incised into a relatively deep narrow bedrock valley that could be amenable to dam construction. The creek has an extensive drainage area and appears to convey considerable winter flows from snowmelt, with little groundwater baseflow (Wanapum Basalt) to sustain flows past June. The initial estimate of winter/spring discharge from Dry Creek is 3,900 acre feet (Table 11). This is a large enough quantity of water to suggest that an on-channel storage facility could be feasible. Most of Dry Creek has been designated as an area of concern for summer fish rearing because of no flow (Raines et. al. 1999). In evaluating an option for on-channel storage in this drainage, the loss of habitat provided by Dry Creek and its tributaries would need to be weighed against the potential benefit to fish in the rest of the Little Klickitat River system. An additional consideration would be how to avoid losing stored water into the alluvium along Dry Creek. A dam constructed within the alluvium could be keyed into the bedrock underlying the alluvium. Water released within or upstream of the alluvium could be piped some distance downstream to reduce losses. Alternatively, some or all of the water could be released into the alluvium earlier in the season and allow it to discharge naturally into the creek at the desired time.

Idlewild Creek. The lower reach of Idlewild Creek is incised into a relatively deep, narrow bedrock valley which could be amenable to dam construction. The valley is also oriented east-west, with a steep southern wall, that may help to shade and maintain lower water temperatures in a potential reservoir there. Although the Idlewild Creek drainage is less than half the size of the Dry Creek drainage, there is evidence from field reconnaissance that it conveys considerable flows during peak events. The estimated winter/spring discharge from Idlewild Creek is 1,600 acre feet (Table 11). As discussed in Section 4.2, this discharge volume may be underestimated. Idlewild appears to have certain positive physical attributes for dam construction, but it is uncertain if the volume of water potentially available from that drainage would warrant such investment. Like Dry Creek, the lower portion of Idlewild Creek is designated a Type 3 water, and cutthroat and rainbow trout have been observed there (Raines et. al. 1999). Therefore, the loss of habitat there would need to be evaluated against the potential habitat benefit to fish in the rest of the Little Klickitat River should the Planning Unit decide to further evaluate on-channel storage in this drainage.

Upper Reaches of Bowman Creek and/or Mill Creek

On-channel impoundment of an upper reach of either Bowman Creek or Mill Creek is a prospective opportunity that could provide potential instream benefit to the Little Klickitat River below the falls at RM 6.1, as well as out-of-stream uses within those respective drainages. Improving late-season flows in Bowman or Mill Creeks would not help temperature impairment in the Little Klickitat headwaters (303d-listed East Prong, West Prong, and Butler Creek), but could improve instream flow and temperature conditions at the mouth of the Little Klickitat (303d-listed in T4N R14E section 9). Bowman Creek is also 303d-listed based on late-season instream flows (T5N R14E section 35; Table 1), so there is potential to improve conditions in that drainage as well. The 16-foot water fall in the Little Klickitat at RM 6.1 is a barrier to migration of anadromous fish, excluding steelhead during high-flow years (WPN 2003). Using storage to increase late-season flows downstream of these falls could improve habitat for chinook, coho, and steelhead, which are all reported to occur there (Sharp et. al. 2000; WPN 2003).

The Bowman and Mill Creek drainages both originate at high elevations (5,800+ feet), and, therefore, convey considerable snowmelt runoff in the winter and early spring. Even by late April 2003, after the runoff peak had passed, measured flows ranged from 4 to 24 cfs in Mill Creek and 16 to 35 cfs in Bowman Creek. Both drainages are also quite long (15+ miles) and cover the largest areas in the subbasin (Table 7), therefore, there is a broad geographic area in which to evaluate potential water storage locations.

Habitat value is an important consideration for evaluating specific on-channel storage options in either of these drainages. The lower half of Bowman Creek is designated as Type 1 and 2 waters, and Type 3 water in most of its upper half (Figure 8). Coho salmon and steelhead spawning has been reported at the lower end of Bowman Creek (Sharp et. al. 2000; WPN 2003). The tributaries to Bowman Creek are designated as Types 4 or 5. Mill Creek is predominantly Type 3 to its upper extent. The lower half of Devils Canyon, a major tributary to Mill Creek, is also designated as Type 3 (Figure 8). As discussed for other options above, evaluation of a specific storage project relying on excess water from an assumed fish-bearing stream (Types 1-3) would require a detailed evaluation of potential net environmental benefit associated with the project.

Specific location of an on-channel dam in either of these drainages would require consideration of several factors, including but not limited to: land ownership and accessibility; habitat potentially lost behind a dam; volume of excess water potentially available above it (higher up the drainage typically equals less water available); stream channel topography and geology (deep narrow bedrock canyon preferred); and the location(s) where the stored water is intended for use.

4.3.4 Off-Channel Impoundment in Little Klickitat Subbasin

As described above, off-channel storage could be used for out-of-stream uses, or instream uses if the stored water can be sufficiently cooled prior to entering the stream. Many small off-channel ponds already exist in this subbasin, used primarily for stock watering and/or irrigation uses.

The same drainages discussed above for on-channel storage are also candidates for diversion into off-channel impoundments, particularly if there are defined water needs in the higher elevation portions of the subbasin. Unlike on-channel storage, the lower elevation streams (e.g., Blockhouse, Spring, and Bloodgood) are also potential candidates for diversion to off-channel storage, if appropriate out-of-stream needs are defined by the Planning Unit. Although these streams are spring-fed, providing a relatively stable baseflow component, they also receive larger volumes of winter/spring runoff that could be diverted for storage.

The option of constructing off-channel storage basins or ponds has greater flexibility than most other options in terms of location and size. Because it involves construction of a diversion structure and piping, instead of a cross-channel dam, it creates considerably less instream impact and would be easier to permit for winter diversion than the on-channel option. The decision of constructing lined vs. unlined basins would depend primarily on the underlying geology and soil types. Because of the flexibility afforded by this option, an off-channel impoundment could likely be designed and constructed to suit most locations in this subbasin, contingent upon acquiring sufficient land to do so. As such, it

is amenable to small-scale storage projects located in close proximity to the intended use for the stored water.

Constructed wetlands may also be a possible storage option in the lower elevation drainages of this subbasin. Water could not be recovered from wetlands as it could be from constructed basins. However, wetlands can provide improvements to water quality, flood control, and off-channel habitat, and may also provide recreational benefits as described in Section 4.3.4. The Central Klickitat Conservation District has recently planted numerous young trees along lower-elevation portions of Spring and Blockhouse Creeks to eventually provide shade and improve temperature conditions in these riparian corridors. Constructing wetlands in other areas of the lower elevation drainages could build upon these riparian restoration activities, and be an additional potential use of water storage in this subbasin. Possible locations for constructed wetlands would be dependent on many factors including land ownership and the combination of topography, geology/soil type, and water inputs to maintain year-round wetland hydrology.

Limitations

Work for this project was performed and this report prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. It is intended for the exclusive use of the WRIA 30 Planning Unit for specific application to the referenced project. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

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Table 4 - Stream Discharge Point Measurements, April 2003

	Measurement Date	Location	Discharge in cfs
Swale Creek Subbasin			
Swale Ck Surface Water			
Swale-3	4/21/03	Swale Ck at Hwy 97 (RM 24.2)	0.6
Swale-2	4/2/03	Swale Ck at Harms Road (RM 12.2)	1.0
Swale-1	4/21/03	Swale Ck Nr Mouth (RM 0.3)	5.1
Little Klickitat Subbasin			
Springs from Simcoe Volcanics			
Bloodgood Springs	4/23/03	Bloodgood Spr (T4N R16E S8; RM 2.4)	7.8
Surface Waters			
Block-1	4/21/03	Blockhouse Ck at RM 3.9	9.4
Block-2	4/21/03	Blockhouse Ck at RM 4.3	4.6
Bloodgood-2	4/23/03	Bloodgood Ck at N. Mill St. (RM 0.4)	8.5
Bowman-1	4/22/03	Bowman Ck at RM 0.5	35.0
Bowman-2	4/22/03	Bowman Ck at RM 3.6	22.7
Bowman-3	4/22/03	Bowman Ck at RM 12.8	20.8
Bowman-4	4/22/03	Bowman Ck at RM 16.8	16.3
Butler-1	4/24/03	Butler Ck at RM 3.7	21.2
Butler-2	4/25/03	Butler Ck at RM 0.1	19.0
Canyon-1	4/22/03	Canyon Ck at RM 5.0	3.9
Canyon-2	4/22/03	Canyon Ck at RM 8.6	1.5
Devil-1	4/23/03	Devils Canyon at RM 2.1	7.1
Dry-1	4/24/03	Mouth of Brimstone Ck (trib to Dry Ck at RM 2.0)	1.9
Dry-2	4/24/03	Dry Ck at RM 2.1	4.7
Dry-3	4/24/03	Dry Ck at RM 1.9	6.4
Dry-4	4/24/03	Dry Ck at RM 0.7	4.6
East Prong-1	4/25/03	East Prong Little Klickitat at RM 0.3	10.0
Idlewild-2	4/24/03	Idlewild Ck at RM 0.7	2.4
Mill-1	4/22/03	Mill Ck at RM 14.5	3.9
Mill-2	4/23/03	Mill Ck at RM 12.7	6.3
Mill-3	4/23/03	Mill Ck at RM 8.4	15.4
Mill-4	4/22/03	Mill Ck at RM 4.0	24.5
West Prong-1	4/24/03	East Fork of West Prong Little Klickitat at RM 4.7	1.1
West Prong-2	4/25/03	West Prong Little Klickitat at RM 0.06	12.9

Notes:
RM: River mile measured from stream mouth.

Table 5 - April 2003 Water Quality Data

Sample	Sample Date	Location	Common Cations				Common Anions			Hardness in mg/l as CaCO3	Iron in mg/L	Manganese in mg/L	Field Parameters		
			Calcium in mg/L	Potassium in mg/L	Magnesium in mg/L	Sodium in mg/L	Bicarbonate Alkalinity in mg/L as CaCO3	Sulfate in mg/L	Chloride in mg/L				Elec. Conduct. in µS/cm	pH	Temp. in °C
Swale Creek Subbasin															
Springs from Basalts															
Spr-1-Swale	4/2/03	North bank @ RM 9.4 (Wanapum	8.58	2.01	6.23	5.29	49.6	2.78	1.38	47.1	1.51	0.0185	80	8.7	10.0
Spr-2-Swale	4/2/03	East bank @ RM 3.4 (Grande Ronde Basalt)	8.86	2.0 U	6.01	4.39	50.2	1.45	0.765	46.9	0.164	0.01 U	100	8.4	12.0
Swale Ck Surface Water															
Swale-3	4/21/03	Swale Ck at Hwy 97 (RM 24.2)	26.6	2.78	14.4	15.3	130	12.8	2.70	125.5	0.852	0.15	270	7.3	11.0
Swale-2	4/2/03	Swale Ck at Harms Road (RM 12.2)	23.0	3.99	10.4	12.3	117	2.96	2.93	100.0	0.899	0.056	230	8.5	10.0
Swale-1A	4/21/03	Swale Ck Nr Mouth (RM 0.3)	14.4	3.03	8.80	8.9	85.2	1.64	1.81	72.1	0.150 U	0.01 U	160	8.7	16.0
Mainstem Klickitat River															
MainStem-1*	4/2/03	Mainstem Klickitat River at Confluence with Swale Ck.	9.78	2.0 U	5.23	6.99	50.4	1.54	1.23	46.0	0.294	0.01 U	100	8.3	9.0

Table 5 - April 2003 Water Quality Data

Sample	Sample Date	Location	Common Cations				Common Anions			Hardness in mg/l as CaCO3	Iron in mg/L	Manganese in mg/L	Field Parameters		
			Calcium in mg/L	Potassium in mg/L	Magnesium in mg/L	Sodium in mg/L	Bicarbonate Alkalinity in mg/L as CaCO3	Sulfate in mg/L	Chloride in mg/L				Elec. Conduct. in µS/cm	pH	Temp. in °C
Little Klickitat Subbasin															
Springs from Wanapum Basalt															
Shelton-1	4/22/03	Shelton Sprg (T6N R14E S35)	7.02	2.0 U	3.14	3.86	32.0	0.40 U	1.08	30.4	6.59	0.0434	50	7.9	7.0
Springs from Simcoe Volcanics															
Presher-1	4/23/03	Presher Sprg (T6N R15E S34)	8.88	2.0 U	5.27	4.33	46.8	0.40 U	0.929	43.8	0.150 U	0.01 U	90	7.6	8.5
Bloodgood-1	4/23/03	Bloodgood Spr (T4N R16E S8)	10.1	2.0 U	5.61	4.31	49.8	0.40 U	1.24	48.3	0.150 U	0.01 U	90	7.7	11.0
Surface Waters															
Block-1	4/21/03	Blockhouse Ck @ RM 3.9	13.1	2.0 U	7.82	5.83	54.0	2.22	0.922	64.8	0.729	0.0403	150	7.8	13.0
Block-2	4/21/03	Blockhouse Ck @ RM 4.3											110	7.8	13.0
Bloodgood-2	4/23/03	Bloodgood Ck @ N. Mill St. (RM 0.4)	10	2.0 U	5.53	4.47	50.8	0.458	1.37	47.7	0.518	0.0113	100	7.9	13.0
Bowman-1	4/22/03	Bowman Ck @ RM 0.5	7.73	2.0 U	4.38	4.47	41.6	0.55	1.07	37.3	0.441	0.01 U	90	7.6	11.0
Bowman-2	4/22/03	Bowman Ck @ RM 3.6											90	7.8	10.0
Bowman-3	4/22/03	Bowman Ck @ RM 12.8											50	7.9	12.0
Bowman-4	4/22/03	Bowman Ck @ RM 16.8											30	8.0	8.0
Butler-1	4/24/03	Butler Ck @ RM 3.7											30	8.1	5.5
Butler-2	4/25/03	Butler Ck @ RM 0.1	4.23	2.0 U	1.99	2.22	22.4	0.40 U	0.502	18.7	0.150 U	0.01 U	40	7.9	5.5
Canyon-1	4/22/03	Canyon Ck @ RM 5.0	7.45	2.0 U	3.31	4.14	35.6	0.40 U	1.09	32.2	0.277	0.0105	80	7.8	11.5
Canyon-2	4/22/03	Canyon Ck @ RM 8.6											60	8.0	13.0
Devil-1	4/23/03	Devils Canyon @ RM 2.1											40	7.8	5.0

Table 5 - April 2003 Water Quality Data

Sample	Sample Date	Location	Common Cations				Common Anions			Hardness in mg/l as CaCO3	Iron in mg/L	Manganese in mg/L	Field Parameters		
			Calcium in mg/L	Potassium in mg/L	Magnesium in mg/L	Sodium in mg/L	Bicarbonate Alkalinity in mg/L as CaCO3	Sulfate in mg/L	Chloride in mg/L				Elec. Conduct. in µS/cm	pH	Temp. in °C
Little Klickitat Subbasin															
Surface Waters (continued)															
Dry-1	4/24/03	Mouth of Brimstone Ck (tributary to Dry Ck @ RM 2.0)	7.52	2.0 U	3.60	2.87	37.4	0.40 U	0.535	33.6	0.150 U	0.01 U	100	8.0	7.0
Dry-2	4/24/03	Dry Ck @ RM 2.1											40	8.0	7.5
Dry-3	4/24/03	Dry Ck @ RM 1.9											70	8.0	7.0
Dry-4	4/24/03	Dry Ck @ RM 0.7											60	8.0	8.0
Dry-5	4/24/03	Dry Ck @ RM 6.2											40	7.9	5.5
East Prong-1	4/25/03	East Prong Little Klickitat @ RM 0.3	8.01	2.0 U	3.80	3.72	40.2	0.40 U	1.01	35.6	0.150 U	0.01 U	70	7.8	7.0
Idlewild-2	4/24/03	Idlewild Ck @ RM 0.7											70	7.7	6.5
Mill-1	4/22/03	Mill Ck @ RM 14.5	5.88	2.0 U	2.85	2.89	28.6	0.40 U	0.586	26.4	0.188	0.01 U	60	7.7	9.0
Mill-2	4/23/03	Mill Ck @ RM 12.7											50	7.8	6.5
Mill-3	4/23/03	Mill Ck @ RM 8.4											60	7.8	8.0
Mill-4	4/22/03	Mill Ck @ RM 4.0	6.58	2.0 U	3.84	3.80	36.4	0.40 U	0.888	32.2	0.741	0.014	70	7.7	10.0
West Prong-1	4/24/03	Mill Ck @ RM 4.0											60	8.1	6.0
West Prong-2	4/25/03	West Prong @ RM ~0.06	5.3	2.0 U	2.36	2.58	26.4	0.40 U	0.567	22.9	0.150 U	0.01 U	50	8.0	6.0

Notes:

*: Erroneously labeled as SWALE-2 in the field and thus reported as such in lab report.

U: Not detected at associated reporting limit.

Carbonate alkalinity and hydroxide alkalinity (anions, not so common) were also analyzed in each sample, but neither was detected in any sample at a 5.0 mg/L detection limit.

Blanks indicate no analysis for that parameter.

RM: River mile measured from stream mouth.

Table 7 - Areas and Top Elevations of Individual Drainages, Swale Creek and Little Klickitat Subbasins

Swale Creek Subbasin		
Drainage	Elevation of Top of Drainage in Feet	Drainage Area in Acres
UN-01	1,611	396
UN-02	2,257	956
UN-03	1,863	447
UN-04	1,729	1,217
UN-05	1,808	39
UN-06	1,775	186
UN-07	1,683	19
UN-08	2,264	555
UN-09	2,208	758
UN-10	2,671	715
UN-11	2,776	1,422
UN-12	2,287	3,911
UN-13	1,601	103
UN-14	1,591	2
UN-15	2,051	1,301
UN-16	1,841	2,821
UN-17	1,621	50
UN-18	1,621	122
UN-19	2,963	1,319
UN-20	2,001	1,185
UN-21	3,074	815
UN-22	2,244	659
UN-23	2,241	2,464
UN-24	2,247	1,619
UN-25	2,011	1,596
UN-26	2,923	1,384
UN-27	2,730	524
UN-28	1,601	235
UN-29	1,923	2,225
UN-30	1,594	51
UN-31	2,129	416
UN-32	1,929	1,299
UN-33	1,581	17
UN-34	2,254	658
UN-35	1,978	1,417
UN-36	1,572	24
UN-37	2,251	1,058
UN-38	1,575	119
UN-39	1,568	9

Swale Creek Subbasin (cont'd)		
Drainage	Elevation of Top of Drainage in Feet	Drainage Area in Acres
UN-40	1,572	26
UN-41	2,126	593
UN-42	1,640	666
UN-43	1,644	311
UN-44	2,083	575
UN-45	2,044	1,102
UN-46	1,726	89
UN-47	2,123	614
UN-48	1,562	1
UN-49	1,558	1
UN-50	1,568	14
UN-51	2,083	1,335
UN-52	1,601	19
UN-53	1,624	55
UN-54	1,644	421
UN-55	1,749	228
UN-56	1,726	121
UN-57	2,100	628
UN-58	3,218	1,112
UN-59	3,218	1,037
UN-60	1,762	290
UN-61	2,080	2,226
UN-62	3,133	716
UN-63	2,487	2,190
UN-64	2,369	962
UN-65	2,369	1,193
UN-66	2,320	738
UN-67	2,648	1,187
UN-68	2,654	1,696
UN-69	2,841	1,142
UN-70	2,844	1,816
UN-71	2,241	3,370
UN-72	2,051	3,283
UN-73	2,051	2,277
UN-74	2,815	2,178
UN-75	2,969	2,605
UN-76	2,923	1,082
UN-77	2,267	5,678
UN-78	3,133	2,226

Table 7 - Areas and Top Elevations of Individual Drainages, Swale Creek and Little Klickitat Subbasins

Little Klickitat Subbasin		
Drainage	Elevation of Top of Drainage in Feet	Drainage Area in Acres
Blockhouse	2,946	7,736
Bloodgood	3,031	3,668
Bowman	5,810	21,356
Butler	5,820	5,704
Canyon	4,163	16,079
Cozy Nook	4,301	2,871
Dry	4,793	5,815
East Prong	4,636	8,226
Highland Canyon	3,812	1,711
Idlewind	4,590	2,384
Jenkins	4,163	6,343
Little Klickitat	2,703	37,559
Mill	5,823	26,933
Spring	4,518	11,962
UN-01	5,344	6,667
UN-02	1,965	1,586
UN-03	2,031	1,740
UN-04	3,927	2,875
West Prong	5,820	6,991

Notes:
UN = Unnamed

Table 8 - Estimates of Average Discharge for Swale Creek for December through April

Catchment	Area in ac	Average Flow in cfs	Average Discharge in ac-ft
UN-01	396	0.3	80
UN-02	956	1.7	500
UN-03	447	0.3	90
UN-04	1,217	0.8	250
UN-05	39	0.1	20
UN-06	186	0.1	40
UN-07	19	0.0	10
UN-08	555	1.0	300
UN-09	758	0.5	160
UN-10	715	1.3	400
UN-11	1,422	2.9	880
UN-12	3,911	7.0	2,100
UN-13	103	0.2	60
UN-14	2	0.0	1
UN-15	1,301	2.0	600
UN-16	2,821	5.0	1,500
UN-17	50	0.1	30
UN-18	122	0.2	70
UN-19	1,319	2.7	800
UN-20	1,185	2.0	600
UN-21	815	1.7	500
UN-22	659	0.5	140
UN-23	2,464	3.0	900
UN-24	1,619	3.0	900
UN-25	1,596	3.0	900
UN-26	1,384	2.7	800
UN-27	524	1.0	300
UN-28	235	0.4	130
UN-29	2,225	4.0	1,200
UN-30	51	0.1	30
UN-31	416	0.5	150
UN-32	1,299	2.3	700
UN-33	17	0.0	10
UN-34	658	0.4	130
UN-35	1,417	2.7	800
UN-36	24	0.0	10
UN-37	1,058	2.0	600
UN-38	119	0.2	60
UN-39	9	0.0	5
UN-40	26	0.0	10
UN-41	593	1.0	300
UN-42	666	1.3	400
UN-43	311	0.6	170
UN-44	575	1.0	300
UN-45	1,102	2.0	600
UN-46	89	0.2	50
UN-47	614	1.1	330
UN-48	1	0.0	1
UN-49	1	0.0	0
UN-50	14	0.0	10
UN-51	1,335	2.3	700
UN-52	19	0.0	10
UN-53	55	0.1	30
UN-54	421	0.7	200
UN-55	228	0.4	120
UN-56	121	0.2	70
UN-57	628	1.0	300
UN-58	1,112	2.0	600
UN-59	1,037	2.0	600
UN-60	290	0.5	160
UN-61	2,226	4.0	1,200
UN-62	716	1.3	400
UN-63	2,190	4.3	1,300
UN-64	962	1.7	500
UN-65	1,193	2.3	700
UN-66	738	1.3	400
UN-67	1,187	2.0	600
UN-68	1,696	3.7	1,100
UN-69	1,142	2.3	700
UN-70	1,816	3.7	1,100
UN-71	3,370	2.3	700
UN-72	3,283	4.0	1,200
UN-73	2,277	4.0	1,200
UN-74	2,178	4.0	1,200
UN-75	2,605	5.3	1,600
UN-76	1,083	2.0	600
UN-77	5,679	11.4	3,400
UN-78	2,226	5.3	1,600
Total	79,914	138	41,000

Notes:

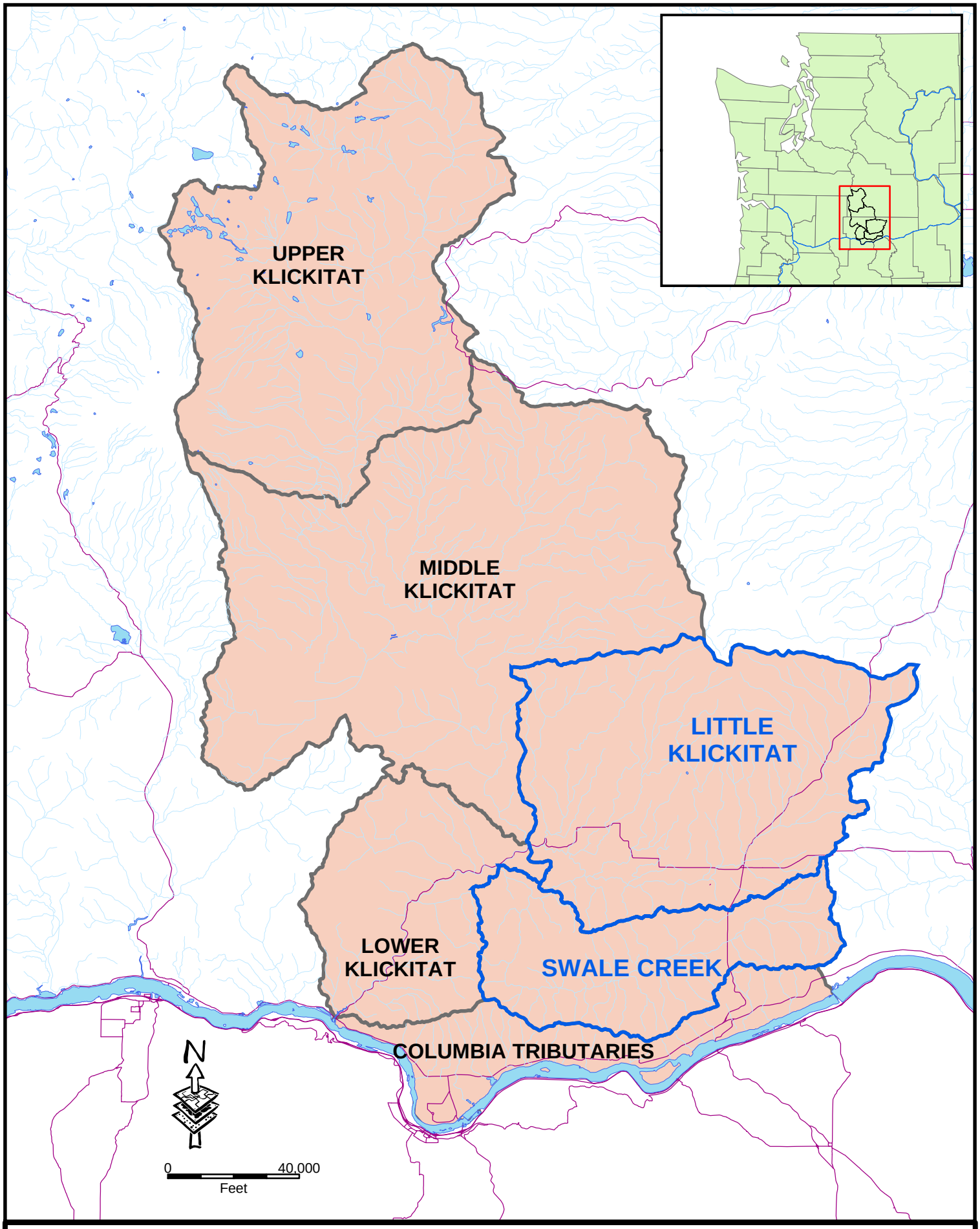
These estimates of discharge are preliminary estimates based on a water balance approach using available precipitation, ET, and recharge estimates. As not all drainages are gaged, actual flows in any drainage may be higher or lower than indicated.

Table 11 - Estimates of Average Discharge for Little Klickitat Subbasin

		Annual		December through May	
Drainage Basin	Area in sq. miles	Est. Average Flow in cfs	Est. Average Discharge in ac-ft	Est. Average Flow in cfs	Est. Average Discharge in ac-ft
Blockhouse	12.1	5	3,900	11.4	3,400
Bloodgood	5.7	3	1,900	5.4	1,600
Bowman	33.4	20	14,000	39.1	12,000
Butler	8.9	6	4,200	12.9	3,900
Canyon	25.1	15	11,000	29.5	8,800
Cozy Nook	4.5	3	1,800	5.5	1,700
Dry	9.1	6	4,100	13.1	3,900
East Prong	12.9	8	6,100	18.6	5,600
Highland Canyon	2.7	1	1,100	3.3	1,000
Idlewild	3.7	2	1,700	5.4	1,600
Jenkins	9.9	6	4,000	12.2	3,700
Mill	42.1	22	16,000	44.6	13,000
Remaining Little Klickitat	58.7	26	19,000	55.4	17,000
Spring	18.7	8	6,100	17.6	5,300
UN-01	10.4	5	3,400	9.8	2,900
UN-02	2.5	1	800	2.3	700
UN-03	2.7	1	900	2.6	800
UN-04	4.5	3	1,800	5.5	1,700
West Prong	10.9	7	5,200	15.8	4,700
Total	278	148	107,000	310	93,300

Notes:

These estimates of discharge are primarily estimates based on observed gage data, actual flows in any drainage may be higher or lower than indicated. Average flows were calculated by multiplying the area of each drainage basin by the flow per unit area from the most representative of these three gages.



Aspect consulting
IN-DEPTH PERSPECTIVE

Swale Creek and Little Klickitat Subbasins
WRIA30 Water Storage Screening Assessment, WA

Figure 1
06-19-03

Legend

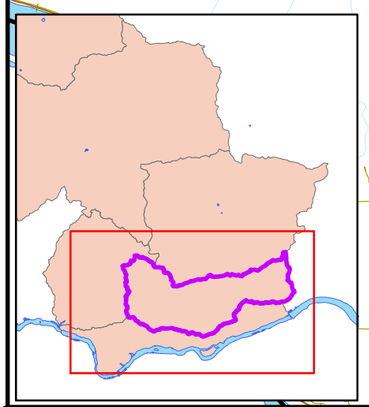
- Township / Range Lines
- Section Lines
- Folds
- Faults

Geologic Type

- Unconsol. Quaternary (alluvium, etc)
- Simcoe Volcanics
- Continental Sedimentary Deposits
- Wanapum Basalts
- Grande Ronde Basalts

NOTE:
geology mapping is 1:100K WA DNR (November 2000)

T4 - R14
T4 - R15
T4 - R16
T4 - R17
T3 - R13
T3 - R14
T3 - R15
T3 - R16
T3 - R17
T2 - R14
T2 - R15
Warwick Fault



N

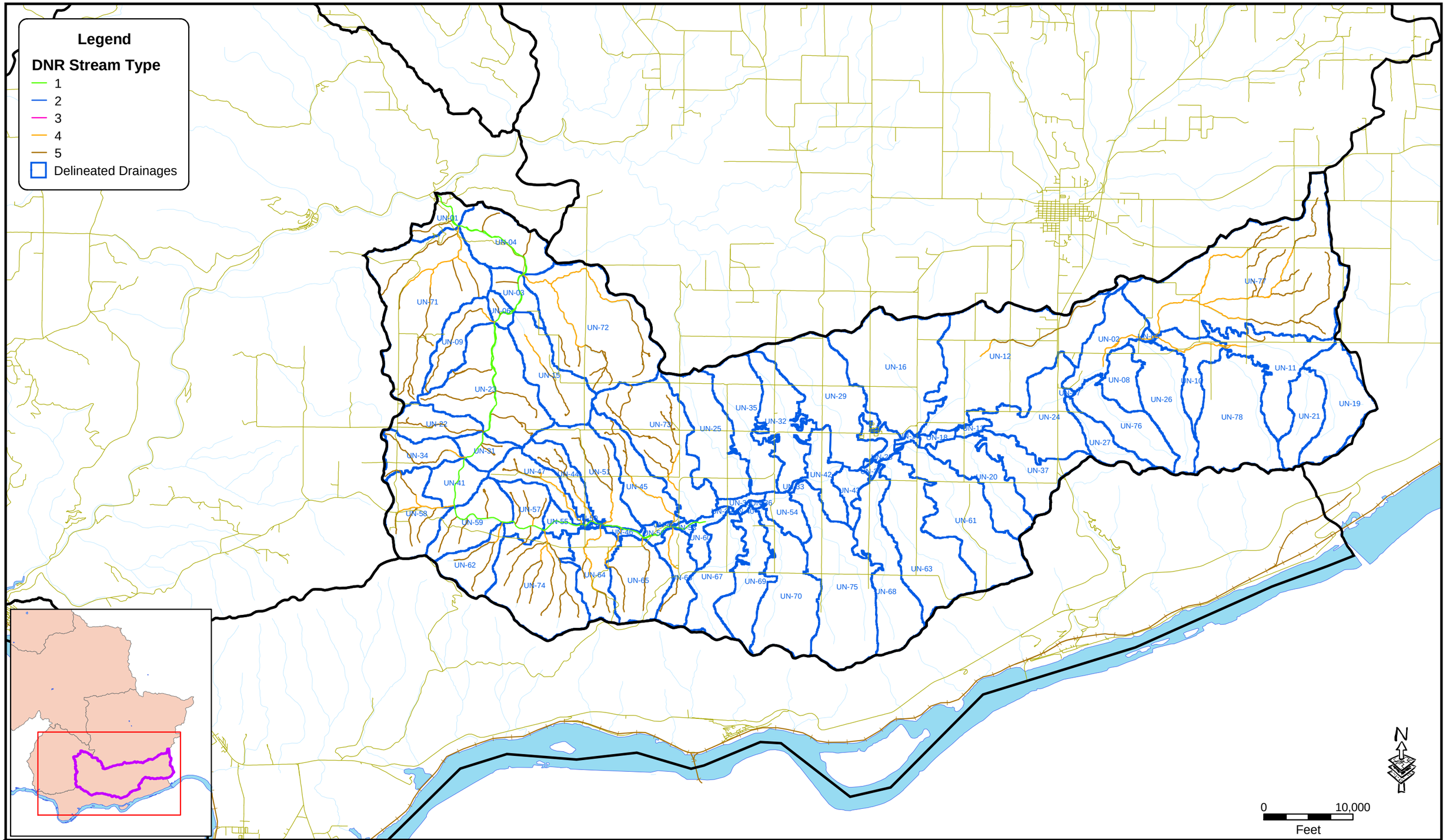
0 10,000
Feet

Aspect consulting
IN-DEPTH PERSPECTIVE

Geologic Map, Swale Creek Subbasin
WRIA30 Water Storage Screening Assessment, WA

Figure 4

06-19-03



Aspect consulting
IN-DEPTH PERSPECTIVE

Stream Types and Drainages, Swale Creek Subbasin
WRIA30 Water Storage Screening Assessment, WA

Figure 5
06-19-03

Legend

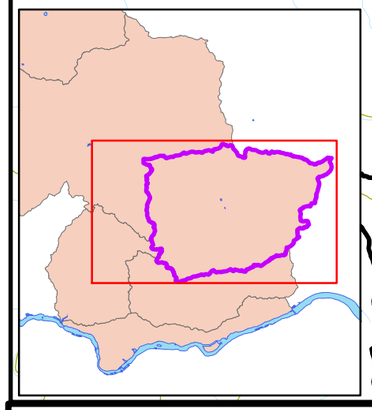
- Township / Range Lines
- Section Lines
- Volcanic Vents
- Folds
- Faults

Geologic Type

- Unconsol. Quaternary (alluvium, etc)
- Simcoe Volcanics
- Continental Sedimentary Deposits
- Wanapum Basalts
- Grande Ronde Basalts

NOTE:
geology mapping is 1:100K WA DNR (November 2000)

T6 - R14
T6 - R15
T6 - R16
T6 - R17
T6 - R18
T5 - R14
T5 - R15
T5 - R16
T5 - R17
T4 - R14
T4 - R15
T4 - R16
T4 - R17
T3 - R15



N

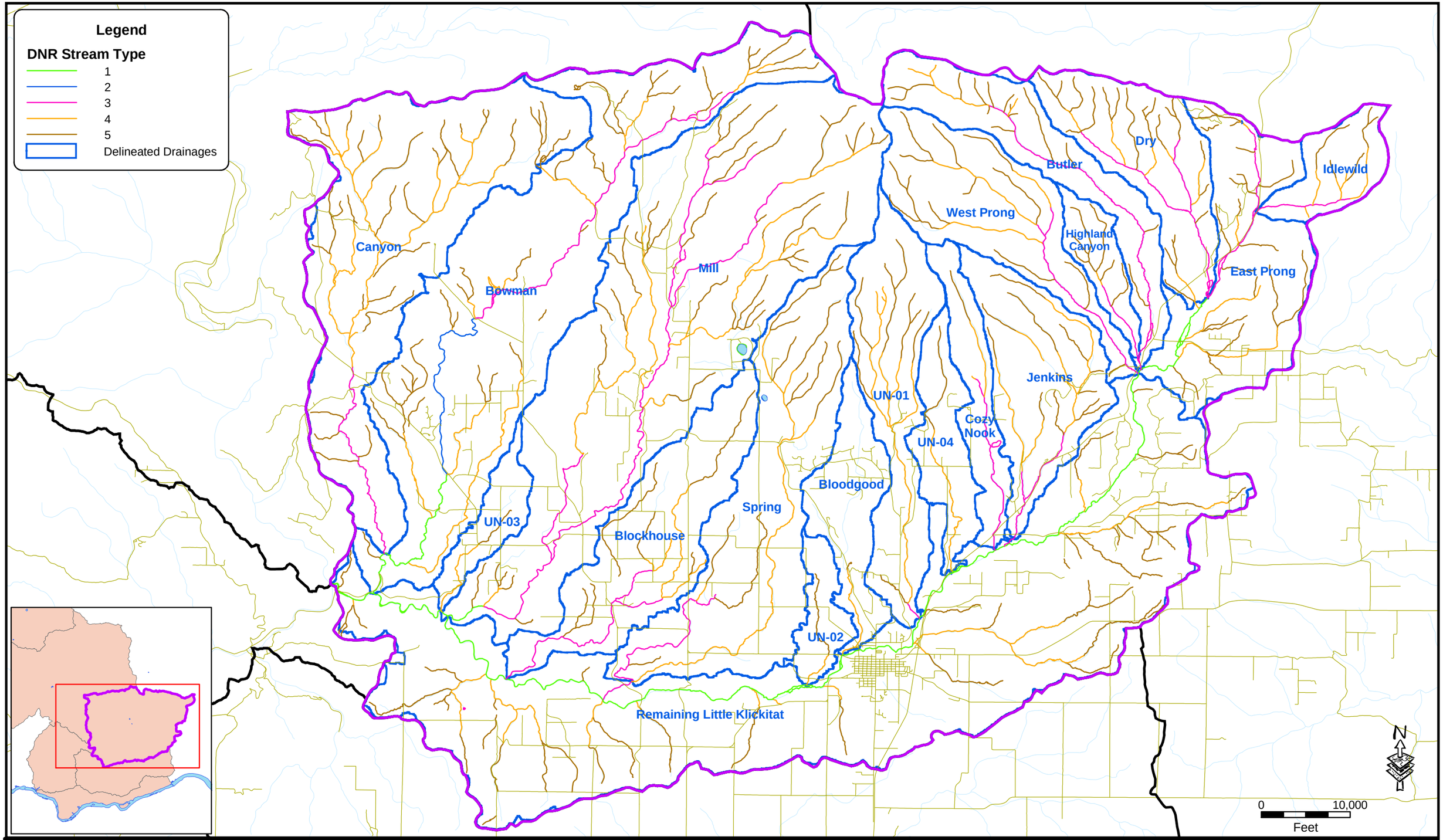
0 10,000
Feet

Aspect consulting
IN-DEPTH PERSPECTIVE

Geologic Map, Little Klickitat Subbasin
WRIA30 Water Storage Screening Assessment, WA

Figure 6

06-19-03



Aspect consulting
IN-DEPTH PERSPECTIVE

Stream Types and Drainages, Little Klickitat Subbasin
WRIA30 Water Storage Screening Assessment, WA

Figure 8

06-19-03

APPENDIX A

Laboratory Certificates of Analysis
North Creek Analytical Inc.

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Anchorage 3209 Denali Street, Anchorage, AK 99503
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Aspect Consulting - Seattle	Project: WRIA 30 Water Storage Assessment	
811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
SPR-1-SWALE	B3D0085-01	Water	04/02/03 09:55	04/03/03 13:00
SPR-2-SWALE	B3D0085-02	Water	04/02/03 14:30	04/03/03 13:00
SWALE-1	B3D0085-03	Water	04/02/03 17:05	04/03/03 13:00
SWALE-2	B3D0085-04	Water	04/02/03 16:15	04/03/03 13:00

North Creek Analytical - Bothell

Jeff Gerdes, Project Manager

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Aspect Consulting - Seattle	Project: WRIA 30 Water Storage Assessment	
811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Total Metals by EPA 6000/7000 Series Methods
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SPR-1-SWALE (B3D0085-01) Water Sampled: 04/02/03 09:55 Received: 04/03/03 13:00									
Calcium	**8.58**	0.250	mg/l	1	3D07016	04/07/03	04/09/03	EPA 6010B	
Iron	**1.51**	0.150	"	"	"	"	04/10/03	"	
Potassium	**2.01**	2.00	"	"	"	"	04/11/03	"	
Magnesium	**6.23**	0.500	"	"	"	"	04/09/03	"	
Manganese	**0.0185**	0.0100	"	"	"	"	"	"	
Sodium	**5.29**	0.250	"	"	"	"	"	"	
SPR-2-SWALE (B3D0085-02) Water Sampled: 04/02/03 14:30 Received: 04/03/03 13:00									
Calcium	**8.86**	0.250	mg/l	1	3D07016	04/07/03	04/09/03	EPA 6010B	
Iron	**0.164**	0.150	"	"	"	"	04/10/03	"	
Potassium	ND	2.00	"	"	"	"	04/11/03	"	
Magnesium	**6.01**	0.500	"	"	"	"	04/09/03	"	
Manganese	ND	0.0100	"	"	"	"	"	"	
Sodium	**4.39**	0.250	"	"	"	"	"	"	
SWALE-1 (B3D0085-03) Water Sampled: 04/02/03 17:05 Received: 04/03/03 13:00									
Calcium	**23.0**	0.250	mg/l	1	3D07016	04/07/03	04/09/03	EPA 6010B	
Iron	**0.899**	0.150	"	"	"	"	04/10/03	"	
Potassium	**3.99**	2.00	"	"	"	"	04/11/03	"	
Magnesium	**10.4**	0.500	"	"	"	"	04/09/03	"	
Manganese	**0.0560**	0.0100	"	"	"	"	"	"	
Sodium	**12.3**	0.250	"	"	"	"	"	"	
SWALE-2 (B3D0085-04) Water Sampled: 04/02/03 16:15 Received: 04/03/03 13:00									
Calcium	**9.78**	0.250	mg/l	1	3D07016	04/07/03	04/09/03	EPA 6010B	
Iron	**0.294**	0.150	"	"	"	"	04/10/03	"	
Potassium	ND	2.00	"	"	"	"	04/14/03	"	
Magnesium	**5.23**	0.500	"	"	"	"	04/09/03	"	
Manganese	ND	0.0100	"	"	"	"	"	"	
Sodium	**6.99**	0.250	"	"	"	"	"	"	

North Creek Analytical - Bothell

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Jeff Gerdes, Project Manager

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Aspect Consulting - Seattle	Project: WRIA 30 Water Storage Assessment	
811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Conventional Chemistry Parameters by APHA/EPA Methods
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SPR-1-SWALE (B3D0085-01) Water Sampled: 04/02/03 09:55 Received: 04/03/03 13:00									
Bicarbonate Alkalinity	**49.6**	5.00	mg/L as CaCO3	1	3D06010	04/06/03	04/06/03	SM 2320B	
Carbonate Alkalinity	ND	5.00	"	"	"	"	"	"	
Hydroxide Alkalinity	ND	5.00	"	"	"	"	"	"	
Total Alkalinity	**49.6**	5.00	"	"	"	"	"	"	
Hardness	**47.1**	1.00	"	"	3D07016	04/07/03	04/09/03	SM 2340B	
SPR-2-SWALE (B3D0085-02) Water Sampled: 04/02/03 14:30 Received: 04/03/03 13:00									
Bicarbonate Alkalinity	**50.2**	5.00	mg/L as CaCO3	1	3D06010	04/06/03	04/06/03	SM 2320B	
Carbonate Alkalinity	ND	5.00	"	"	"	"	"	"	
Hydroxide Alkalinity	ND	5.00	"	"	"	"	"	"	
Total Alkalinity	**50.2**	5.00	"	"	"	"	"	"	
Hardness	**46.9**	1.00	"	"	3D07016	04/07/03	04/09/03	SM 2340B	
SWALE-1 (B3D0085-03) Water Sampled: 04/02/03 17:05 Received: 04/03/03 13:00									
Bicarbonate Alkalinity	**117**	5.00	mg/L as CaCO3	1	3D06010	04/06/03	04/06/03	SM 2320B	
Carbonate Alkalinity	ND	5.00	"	"	"	"	"	"	
Hydroxide Alkalinity	ND	5.00	"	"	"	"	"	"	
Total Alkalinity	**117**	5.00	"	"	"	"	"	"	
Hardness	**100**	1.00	"	"	3D07016	04/07/03	04/09/03	SM 2340B	
SWALE-2 (B3D0085-04) Water Sampled: 04/02/03 16:15 Received: 04/03/03 13:00									
Bicarbonate Alkalinity	**50.4**	5.00	mg/L as CaCO3	1	3D06010	04/06/03	04/06/03	SM 2320B	
Carbonate Alkalinity	ND	5.00	"	"	"	"	"	"	
Hydroxide Alkalinity	ND	5.00	"	"	"	"	"	"	
Total Alkalinity	**50.4**	5.00	"	"	"	"	"	"	
Hardness	**46.0**	1.00	"	"	3D07016	04/07/03	04/09/03	SM 2340B	

North Creek Analytical - Bothell

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811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Anions by EPA Method 300.0
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SPR-1-SWALE (B3D0085-01) Water Sampled: 04/02/03 09:55 Received: 04/03/03 13:00									
Chloride	**1.38**	0.400	mg/l	1	3D09017	04/08/03	04/08/03	EPA 300.0	
Sulfate	**2.78**	0.400	"	"	"	"	"	"	
SPR-2-SWALE (B3D0085-02) Water Sampled: 04/02/03 14:30 Received: 04/03/03 13:00									
Chloride	**0.765**	0.400	mg/l	1	3D09017	04/08/03	04/08/03	EPA 300.0	
Sulfate	**1.45**	0.400	"	"	"	"	"	"	
SWALE-1 (B3D0085-03) Water Sampled: 04/02/03 17:05 Received: 04/03/03 13:00									
Chloride	**2.93**	0.400	mg/l	1	3D09017	04/08/03	04/08/03	EPA 300.0	
Sulfate	**2.96**	0.400	"	"	"	"	"	"	
SWALE-2 (B3D0085-04) Water Sampled: 04/02/03 16:15 Received: 04/03/03 13:00									
Chloride	**1.23**	0.400	mg/l	1	3D09017	04/08/03	04/08/03	EPA 300.0	
Sulfate	**1.54**	0.400	"	"	"	"	"	"	

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Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Total Metals by EPA 6000/7000 Series Methods - Quality Control
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch 3D07016: Prepared 04/07/03 Using EPA 3010A										
Blank (3D07016-BLK1)										
Calcium	ND	0.250	mg/l							
Iron	ND	0.150	"							
Magnesium	ND	0.500	"							
Manganese	ND	0.0100	"							
Potassium	ND	2.00	"							
Sodium	ND	0.250	"							
LCS (3D07016-BS1)										
Calcium	5.02	0.250	mg/l	5.00		100	80-120			
Iron	5.20	0.150	"	5.00		104	80-120			
Magnesium	5.16	0.500	"	5.00		103	80-120			
Manganese	5.07	0.0100	"	5.00		101	80-120			
Potassium	11.5	2.00	"	10.0		115	80-120			
Sodium	5.40	0.250	"	5.00		108	80-120			
LCS Dup (3D07016-BSD1)										
Calcium	5.07	0.250	mg/l	5.00		101	80-120	0.991	20	
Iron	5.15	0.150	"	5.00		103	80-120	0.966	20	
Magnesium	5.12	0.500	"	5.00		102	80-120	0.778	20	
Manganese	5.08	0.0100	"	5.00		102	80-120	0.197	20	
Potassium	10.1	2.00	"	10.0		101	80-120	13.0	20	
Sodium	5.24	0.250	"	5.00		105	80-120	3.01	20	
Matrix Spike (3D07016-MS1)					**Source: B3D0043-02**					
Calcium	329	0.250	mg/l	5.00	315	280	75-125			Q-15
Iron	7.72	0.150	"	5.00	2.90	96.4	75-125			
Magnesium	40.6	0.500	"	5.00	35.6	100	80-120			
Manganese	6.22	0.0100	"	5.00	1.38	96.8	75-125			
Potassium	20.3	2.00	"	10.0	9.76	105	80-120			
Sodium	262	1.25	"	5.00	259	60.0	75-125			Q-15

North Creek Analytical - Bothell

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811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Total Metals by EPA 6000/7000 Series Methods - Quality Control
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch 3D07016: Prepared 04/07/03 Using EPA 3010A										
Matrix Spike Dup (3D07016-MSD1)					**Source: B3D0043-02**					
Calcium	317	0.250	mg/l	5.00	315	40.0	75-125	3.72	20	Q-15
Iron	7.74	0.150	"	5.00	2.90	96.8	75-125	0.259	20	
Magnesium	40.6	0.500	"	5.00	35.6	100	80-120	0.00	20	
Manganese	6.12	0.0100	"	5.00	1.38	94.8	75-125	1.62	20	
Potassium	20.1	2.00	"	10.0	9.76	103	80-120	0.990	20	
Sodium	271	1.25	"	5.00	259	240	75-125	3.38	20	Q-15
Post Spike (3D07016-PS1)					**Source: B3D0043-02**					
Calcium	310	0.250	mg/l	5.00	315	-100	75-125			Q-15
Iron	7.62	0.150	"	5.00	2.90	94.4	75-125			
Magnesium	39.2	0.500	"	5.00	35.6	72.0	75-125			Q-15
Manganese	5.98	0.0100	"	5.00	1.38	92.0	75-125			
Potassium	21.4	2.00	"	10.0	9.76	116	75-125			
Sodium	260	1.25	"	5.00	259	20.0	75-125			Q-15

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Aspect Consulting - Seattle	Project: WRIA 30 Water Storage Assessment	
811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch 3D06010: Prepared 04/06/03 Using General Preparation										
Blank (3D06010-BLK1)										
Bicarbonate Alkalinity	ND	5.00	mg/L as CaCO3							
Carbonate Alkalinity	ND	5.00	"							
Hydroxide Alkalinity	ND	5.00	"							
Total Alkalinity	ND	5.00	"							
LCS (3D06010-BS1)										
Total Alkalinity	52.8	5.00	mg/L as CaCO3	50.0		106	90-110			
LCS Dup (3D06010-BSD1)										
Total Alkalinity	53.0	5.00	mg/L as CaCO3	50.0		106	90-110	0.378	20	
Duplicate (3D06010-DUP1)					**Source: B3D0085-01**					
Bicarbonate Alkalinity	49.0	5.00	mg/L as CaCO3		49.6			1.22	6	
Carbonate Alkalinity	ND	5.00	"		ND			NA	6	
Hydroxide Alkalinity	ND	5.00	"		ND			NA	6	
Total Alkalinity	49.0	5.00	"		49.6			1.22	6	
Batch 3D07016: Prepared 04/07/03 Using EPA 3010A										
Blank (3D07016-BLK1)										
Hardness	ND	1.00	mg/L as CaCO3							
LCS (3D07016-BS1)										
Hardness	33.8	1.00	mg/L as CaCO3	33.1		102	85-115			
LCS Dup (3D07016-BSD1)										
Hardness	33.8	1.00	mg/L as CaCO3	33.1		102	85-115	0.00	20	

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Aspect Consulting - Seattle	Project: WRIA 30 Water Storage Assessment	
811 1st Avenue, Suite 480	Project Number: Not Provided	**Reported:**
Seattle WA, 98104	Project Manager: Steve Germiat, PG, CGWP	04/18/03 08:53

Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch 3D07016: Prepared 04/07/03 Using EPA 3010A										
Matrix Spike (3D07016-MS1)					**Source: B3D0043-02**					
Hardness	989	1.00	mg/L as CaCO3	33.1	932	172	80-120			Q-01
Matrix Spike Dup (3D07016-MSD1)					**Source: B3D0043-02**					
Hardness	960	1.00	mg/L as CaCO3	33.1	932	84.6	80-120	2.98	20	

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Anions by EPA Method 300.0 - Quality Control
North Creek Analytical - Bothell

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch 3D09017: Prepared 04/08/03 Using General Preparation										
Blank (3D09017-BLK1)										
Chloride	ND	0.400	mg/l							
Sulfate	ND	0.400	"							
LCS (3D09017-BS1)										
Chloride	2.05	0.400	mg/l	2.00		102	90-110			
Sulfate	6.04	0.400	"	6.00		101	90-110			
LCS Dup (3D09017-BSD1)										
Chloride	2.06	0.400	mg/l	2.00		103	90-110	0.487	20	
Sulfate	6.04	0.400	"	6.00		101	90-110	0.00	20	
Duplicate (3D09017-DUP1)					**Source: B3C0699-01**					
Sulfate	24.3	2.00	mg/l		24.3			0.00	25	
Duplicate (3D09017-DUP2)					**Source: B3D0085-01**					
Chloride	1.36	0.400	mg/l		1.38			1.46	25	
Sulfate	2.81	0.400	"		2.78			1.07	25	
Matrix Spike (3D09017-MS1)					**Source: B3C0699-01**					
Sulfate	30.6	2.00	mg/l	6.00	24.3	105	58-135			
Matrix Spike (3D09017-MS2)					**Source: B3D0085-01**					
Chloride	3.28	0.400	mg/l	2.00	1.38	95.0	52-134			
Sulfate	8.71	0.400	"	6.00	2.78	98.8	58-135			

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Notes and Definitions

Q-01	The spike recovery for this QC sample is outside of established control limits. Review of associated batch QC indicates the recovery for this analyte does not represent an out-of-control condition for the batch.
Q-15	Analyses are not controlled on matrix spike RPD and/or percent recoveries when the sample concentration is significantly higher than the spike level.
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference

North Creek Analytical - Bothell

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.

Jeff Gerdes, Project Manager