6. HYDROLOGY – GROUND WATER

Groundwater is an important resource in the Methow Valley, often the subject of controversy and sometimes misunderstood because it is "unseen water." The Methow has been a proving ground for the concept and regulatory issues surrounding "hydraulic continuity" in Washington State.

6.1 Background Issues

Background issues related to groundwater include:

- The geology of the basin has created large alluvial aquifers in the mainstem Methow, and the high permeability of the soils provides for high and sustained recharge rates. Tributaries to the Methow support smaller alluvial aquifers, but these also are easily recharged because of soil conditions.
- Run-off from bedrock areas on the margins of the alluvial aquifers provides groundwater recharge, particularly during spring melt. The Methow river and its tributaries also provide recharge to aquifers, particularly in the upper reaches of the alluvial system.
- The mainstem Methow and its tributaries become highly dependent on groundwater discharge (baseflow) during the late summer, when the snowpack has melted and there is little precipitation. Therefore, characterizing the water present in the basin as groundwater is important to watershed planning.
- Irrigation transportation losses that occur as a result of leakage from canals or on-farm practices enter the groundwater system before moving to adjacent streams. The influence of irrigation recharge on groundwater levels, resulting flow patterns, and eventual discharge to streams is important to watershed planning.
- The seasonality and prolific nature of the aquifers in the Methow Basin create dynamic fluctuations and interactions with surface water. The components of groundwater flow are therefore important in order to understand where and how much groundwater is present at any point in time.
- Surface water is in close communication with groundwater in the Methow. This has resulted in a regulatory policy that essentially equates groundwater withdrawals to surface water withdrawals. The regulatory limitations placed on surface waters through Washington Administrative Code effectively translate to limitations on groundwater withdrawal, including the allocation targets for exempt uses established from the "2 cfs rule."

6.2 Objective and Level of Detail

The objective of the groundwater Level 1 presentation is to describe the available data and present some basic conceptual issues related to groundwater flow and water management, including sub-basin aggregates of: aquifer extent, aquifer properties, groundwater flow rates, and groundwater storage capacity.

6.3 Existing Data

The primary sources of existing data are the following four reports:

EMCON, 1993. Draft Upper Methow Groundwater Management Hydrogeological Summary Report.

> This study was part of the Groundwater Advisory Committee (GWAC) Planning process, and focused on the prolific aquifer that exists above Weeman Bridge. A total of 12 monitoring wells were installed in the Upper Methow sub-basin, groundwater and surface water data were collected, geophysical explorations were conducted, and a deep test well was installed and tested to evaluate aquifer conditions.

Golder Associates, 1991. Groundwater flow modeling of the Upper Methow aquifer.

> This study included the development of a 2-dimensional transient groundwater flow model of the Upper Methow aquifer using the USGS modeling code MODFLOW. The model was used to simulate the effects of groundwater withdrawals on aquifer levels and streamflows. Since the model was time-varying (transient), the interaction of groundwater and surface water during the late summer, when streamflows often cease, was simulated.

Montgomery Water Group, 1996. Methow Valley Irrigation District Water Supply Facility Plan

> This study was a baseline inventory of wells in the vicinity of the MVID canal system, encompassing portions of the Twisp, Middle Methow, and Lower Methow sub-basins. A total of 124 well logs were reviewed and basic parameters were summarized. An estimate of down-valley flow was provided as a basis for determining the safe yield of the aquifer. A memorandum dated May 11, 1998, from Buell and Associates provides a review of this Plan. The memorandum identified two possible errors in the calculations of down-valley flow (which was used to determine safe aquifer yield). The hydraulic conductivity used was 0.001 ft/minute, which is about one-order of magnitude lower than typical gravel aquifers. Cross-sectional aquifer areas for the Lower Methow of 130,000 to 300,000 feet^2 were used in the calculations, and references of total aquifer thickness of greater than 100 feet were indicated. This would indicate a valley width of only 1,300 to 3,000 feet. This document utilizes the basic data presented in this report but not the calculations.

HWA Geosciences, 2001. Aquifer Testing and Hydrogeological Evaluation, Methow Valley Irrigation District

> This study included the installation and testing of three high capacity groundwater wells adjacent to the MVID canal system. The wells were located in

the Lower Methow sub-basin. The Planning Unit would like to have this document peer reviewed prior to formal acceptance due to QA/QC concerns. However, a review of the documentation provided by WDOE did not reveal obvious errors in the data or analysis.

6.4 New Data and Definitions

The US Geological Survey is preparing a groundwater assessment that is based on a compilation of well logs on file with the Washington Department of Ecology, coupled with baseline field measurements of water levels and water quality. A detailed study area in the Twisp sub-basin has been established to look at local-scale groundwater conditions. The results of these studies are not yet available.

The term baseflow is commonly used in groundwater hydrology. This can be confusing since there are regulatory definitions of baseflow which do not reflect the scientific use of the work in groundwater hydrology. The scientific definition of baseflow is used exclusively in this section:

- Streamflow includes both surface runoff and baseflow. Baseflow is water that enters the stream from sources other than direct run-off of precipitation, primarily groundwater. Since it constitutes most of the streamflow during low flow periods, it is an important parameter in evaluating groundwater systems and their interaction with surface water.

When baseflow is used in a regulatory sense, it is termed “regulatory baseflow”:

- Regulatory baseflows are defined in the Water Resources Act of 1971. Baseflows are the flows administratively established “necessary to provide for the preservation of wildlife, fish, scenic, aesthetic, and other environmental values, and navigational values”.

Regulatory baseflow and instream flow are similar in definition. In the current working legislative draft for instream flow guidance, “instream flow” is now specifically defined as:

- A level of stream flow or lake level designated by rule that establishes the rate of stream flow or lake level that cannot be further diminished by water rights issued subsequent to the adoption of the instream flow rule. It is the level of stream flow or lake level which, when not met or exceeded, triggers the department’s authority to regulate or otherwise interrupt the exercise of water rights that are conditioned to the instream flow.

6.5 Presentation of Current Conditions

For the purposes of watershed planning, the most important aspects of groundwater to understand are largely conceptual. The Methow Basin aquifer is basically a closed, bounded, linear system, often of considerable depth and extent. Surface water is in close interaction with groundwater in the Methow, and virtually all of the groundwater within the basin is discharged to the Methow or its tributaries. This system is considerably simpler than, for example, the sprawling Columbia Basalt Aquifer system or Puget Sound Lowland Aquifer system, where aquifers commonly cross between watershed boundaries, and water uses are highly variable in magnitude and duration. Therefore, the critical conceptual aspects of groundwater that relate to watershed planning in the basin are:

- The extent, boundaries and general hydraulic properties of the aquifer system;
- The difference between groundwater flow and groundwater storage;
- The parameters that control the relationship between groundwater recharge and groundwater discharge;
- The parameters that control the exchange of water between aquifers and streams; and
- The source of water to wells during pumping.

6.5.1 Aquifer Extent and Properties

The primary aquifers in the Methow Basin are within alluvial sediments, which are generally located in valley bottoms. Geologic mapping from the USFS GIS library (Figure 6-1) depicts simplified geologic units, including alluvium, based on DNR 1:100,000 scale maps. Table 6-1 summarizes the primary groundwater parameters in each sub-basin of the Methow. The parameters presented in the table are a combination of direct references to available reports and professional judgment, in cases where detailed studies are not available.

The aerial extent of alluvial sediments is assumed to represent the lateral extent of aquifers in the Methow Mainstem. The aerial extent of the Twisp and Chewuch River valleys is assumed to represent the lateral extent of aquifers in those tributary basins. Aquifer thickness has been estimated by EMCON (1993), Golder (1991), Montgomery (1996), and HWA (2001) based on well logs and geophysical surveys.

Groundwater is described in terms of several basic physical properties, the most important being the transmissivity and storativity. Transmissivity describes the ability of water to flow through an aquifer. Storativity describes the volume of water that is present in the aquifer as a function of the water level in the aquifer. Groundwater flow rates through an aquifer are related to transmissivity. Groundwater volumes present in an aquifer are related to the aquifer capacity and porosity.

As shown on Table 6-1, aquifer transmissivity ranges from 60,000 ft^2/day to 140,000 ft^2/day. This is based on testing in the Upper and Lower Methow sub-basins only. An estimate of 40,000 ft^2/day is assigned to tributary basins, and 60,000 ft^2/day is assigned to the Middle Methow. The full thickness of aquifers in the Methow is not known, and very few wells extend to bedrock. Thickness in the Upper Methow is estimated to exceed 800 feet (EMCON, 1989). Thickness in the Lower Methow is estimated at 150 to 200 feet (Montgomery Water Group, 1996). Aquifer thickness in the tributary sub-basins and the Middle Methow are estimates only. Hydraulic gradients appear to follow the topography, which is on the order of 30 to 40 feet per mile. This is equal to a dimensionless gradient of 0.0056 to 0.0075.

Downvalley flow rates are calaculated based on Darcy's Law by multiplying the cross-sectional area of the aquifer (width x depth) by the hydraulic conductivity and the hydraulic gradient. Downvalley flow in the upper mainstem is near 100 cfs. In the lower mainstem, downvalley flow is on the order of 30 cfs. In the tributary sub-basins, downvalley flow is 16 to 30 cfs.

Total aquifer volume is based on the geometry of the aquifer. Groundwater storage capacity is equal to the aquifer volume multiplied by porosity, and represents the volume of water within the aquifer system. Porosity is estimated at 20%, which is typical for coarse sand and gravel materials. Total groundwater storage capacity is estimated at over 2.9 million acre-feet (Table 6-1).

6.5.2 Groundwater Recharge and Discharge

Groundwater flows from high elevation recharge areas to lower elevation discharge areas. As described above, the rate of flow is related to aquifer properties. The location of these recharge and discharge areas is related to the overall shape and structure of the aquifer. Constrictions in an aquifer, changes in ground surface elevation or bottom elevation of the aquifer; changes in aquifer transmissivity; and other geologic conditions all affect where recharge and discharge occurs.

In the Methow, groundwater recharge occurs via four pathways:

1. Direct infiltration of precipitation on the valley floor;
2. Infiltration of run-off along the valley margins
3. Infiltration of streamflow through permeable streambeds; and
4. Infiltration from irrigation canals.

Groundwater discharge in the Methow occurs:

1. In low-lying areas, typically surface water bodies or wetlands, where the topography intersects the elevation of the water table;
2. In areas where geologic structures constrict the aquifer and cause upwelling. This is known to occur between Weeman Bridge and Winthrop, at the mouth of the Chewuch River, and between Twisp and Black Canyon; and
3. From wells that pump groundwater.

Estimating recharge is necessary for watershed analysis to assess the amount of water present in the groundwater system. Typical methods for estimation of recharge or discharge are intended for the analysis of flow systems that are driven by areally diffuse recharge events that are roughly concurrent with peaks in streamflow. Two commonly used methods are baseflow recession and observed groundwater level fluctuations:

1. Fluctuations in groundwater level reflect the seasonal inflow and outflow of water to the groundwater system. Multiplying the annual water-level fluctuation by the total area of the aquifer and its storage coefficient reflects the volume of annual recharge. Seasonal groundwater level fluctuations range from over 20 feet in the upper basin to less than 10 feet in the lower basin. The combined aerial extent of aquifers in the Methow is about 26,000 acres, and the estimated porosity is 20%. Basin-scale aerial recharge is estimated at over 100,000 acre-feet (AF) using this methodology.
2. Baseflow recession is the portion of a streamflow hydrograph where streamflows vary primarily as a function of groundwater discharge. In the Methow, baseflow recession becomes very apparent in the hydrograph in the late summer and early fall. Evaluation of this portion of the streamflow hydrgraph can be used to estimate groundwater recharge if the streamflow gaging station at the downstream end can be considered the only point of outflow. This is a reasonable assumption if most groundwater recharge discharges to streams, rather than through pumping wells or through evapotranspiration. Groundwater discharge determined from baseflow recession is assumed to be equal to the total recharge to the basin. Baseflow estimates were developed by Ecology (1999) for the Methow and are shown in Table 6-2. These are the scientific baseflows, not regulatory baseflows. Monthly baseflow statistics were not computed during spring thaw (March - June) because of snowmelt influences during that period. In general, maximum monthly baseflow occurs in August. Minimum monthly baseflow tends to occur in January on the Methow River and between September and February on other tributaries. Baseflow is estimated to make up the largest percentage of streamflow on the Methow River in August, but on other tributaries maximum baseflow as a percentage of streamflow usually occurs in January or February. Total estimated annual recharge (Table 6-1) is based on the mean September baseflow estimate at Pateros of 475 cfs (360 to 700 cfs). This is equivalent to about 340,000 acre-feet (AF).

Using these methods independently may not be reliable for flow systems dominated by snowmelt runoff and recharge from losing streams. The baseflow method accounts for stream-aquifer interaction but underestimates aerial recharge from precipitation that increases groundwater storage. The fluctuation method accounts for aerial recharge, but underestimates stream-aquifer interaction. Because stream-aquifer interaction is known to be significant in the Methow, the estimate of 340,000 AF is considered to be most representative of groundwater recharge in the basin.

6.5.3 Groundwater Flowpaths

Groundwater moves from recharge to discharge areas along a number of different flow paths. A flow path is the direction and rate that groundwater moves from a recharge area to a discharge area. Figure 6-2 shows conceptually the various paths that groundwater takes as it moves through the subsurface. Characterizing these flow paths is often difficult, but typically subdivided into four categories:

1. Shallow flow paths are those that typically connect recharge and discharge areas that are relatively close together. Accurate characterizing of shallow flow paths generally requires groundwater level information from wells screened across the water table and spaced on the order of 10's to 100's of feet. Shallow flowpaths are sensitive to local conditions, such as subtle changes in topography or aquifer transmissivity. Wetlands are often sustained by groundwater that has a shallow flow path from the recharge to discharge area.
2. Intermediate flow paths are flowpaths that characterize the principal horizontal flow directions in an aquifer. They typically generate a view of the basin-scale flow patterns in an aquifer, describing the primary recharge and discharge areas and regional hydraulic gradients.
3. Deep flow paths are flow paths that are dependent not only on the horizontal movement of groundwater, but also on vertical component of groundwater flow and stratification (or anisotropy) in the aquifer system. Deep flow paths typically connect regional upland recharge areas with strong downward vertical gradients, with regional lowland discharge areas with strong upward gradients. Accurate characterizing of deep flow paths generally requires deep monitoring wells spaced on the order of 1,000s of feet, and a comparison with hydraulic heads for intermediate and/or shallow flowpaths.
4. Hyporheic flow paths. These are a specific type of shallow flow path related to the zone in which groundwater mixes with streamflow, termed the hyporheic zone. Ecologists have cited the importance of the hyporheic zone, but a consistent single definition has not been adapted by various scientific disciplines (White, 1993). In concept, hyporheic flow paths are very short, essentially connecting upstream surface water flow with downstream shallow upwelling, primarily along the longitudinal gradient of the stream channel. Flow paths perpendicular to the stream channel that are exclusively related to the hyporheic zone typically do not extend very far from the stream channel.

In the Methow, a fifth category of flowpath is present as a result of leakage from irrigation canals. Canal leakage contributes to multiple flow paths, depending largely on the location of the canal relative to adjacent discharge areas. A canal close to a stream or wetland will likely influence hyporheic flow paths, but not the longer shallow or intermediate flow paths. A canal farther from a stream or wetland will likely influence shallow flowpaths, but still may not influence intermediate or regional flowpaths. In all cases, the degree to which the flowpath is altered from a "natural" state (i.e. both the direction and rate of groundwater flow) is dependent on the magnitude of canal leakage relative to the magnitude of groundwater flow along a given reach.

Currently there are sufficient sampling locations and data to generally describe intermediate flowpaths in the Methow aquifer system. In some areas, shallow flow paths and associated subtle recharge/discharge relationships could be described, where well spacings are sufficiently shallow. There are not currently sufficient sampling locations data to describe deep and hyporheic flow paths. A map of groundwater flow directions and flow paths in the Methow is being developed as part of the USGS Groundwater Study.

6.5.4 Stream-Aquifer Interaction

The magnitude, timing and duration of stream-aquifer interactions depends on regional recharge/discharge relationships and local flow path conditions in the vicinity of the stream system. In the Methow, stream-aquifer interaction can be related to both regional and local conditions.

At a local scale, the degree of stream-aquifer interaction depends on the groundwater level relative to the level of the streambed. When groundwater elevation exceeds stream elevation at the stream, groundwater discharges to the stream. When groundwater elevation is less than the stream elevation at the stream, the stream infiltrates to groundwater. Figure 6-3 shows groundwater and surface water elevations in the vicinity of Weeman Bridge from 1991. It shows that the relative elevations of the groundwater and stream vary during the year. In the vicinity of this well, therefore, the stream can be gaining or losing.

At a regional scale, stream-aquifer interaction is evident in streamflow patterns (gains or losses) between gage sites. Streamflow infiltrates to groundwater above Weeman Bridge, causing the riverbed to dry up, even on years with average snowmelt. The magnitude of infiltration is significant and causes the Methow River to disappear at various locations above Weeman Bridge during the late summer. Much of this flow re-surfaces between Weeman Bridge and Winthrop. Streamflow increases of 95 cfs were documented by the USGS in September 2001 between Weeman Bridge and Wolf Creek (Kimbrough et. al., 2002). There are no significant surface water inputs to the Methow River on this reach. The cause of this upwelling is probably related to a geologic fault (Boesel Fault) that crosses the valley below Weeman Bridge. Geophysical surveys presented in the Groundwtaer Management Plan (EMCON, 1989) suggest that the thickness of the aquifer decreases by several hundred feet downvalley of this geologic structure. This sudden decrease in aquifer thickness would cause upwelling of groundwater to the Methow River. The upwelling of groundwater between Weeman Bridge and Winthrop provides a sustained year-round flow and creates high quality habitat for fish. This reach of the Methow River consistently produced the highest density of Chinook salmon redds in the basin (WSCC, 2000).

Between Winthrop and Benson Creek there are alternating areas of minor (i.e. less than 10% of streamflow) gaining and losing conditions in the Methow River. It is not possible to accurately determine groundwater discharge based on these data.

Below Benson Creek, there is significant upwelling of groundwater to surface water, as the alluvial sediments pinch out approaching Black Canyon. Streamflow increases of 32 cfs were documented by the USGS in September 2001 between Benson Creek and Burma Road (Kimbrough et. al., 2002). Libby Creek and Gold Creek contributed about 8 cfs of streamflow during this period, based on MBPU stream gaging during this period. Therefore, groundwater discharge was on the order of 24 cfs during this period.

6.5.5 Groundwater Storage

Groundwater flowpaths and stream-aquifer interactions are dynamic responses of the aquifer system to groundwater recharge and discharge, typically described using rate variables (variables with time in the units). Groundwater storage describes the volume of water present in an aquifer. Groundwater storage is the volume of water that resides within the pore spaces of the aquifer, and is therefore proportional to the size of the aquifer and its overall porosity. Groundwater storage is filled and drained in response to seasonal recharge patterns. During high recharge periods, storage is filled and groundwater levels rise. During low recharge periods, storage is drained and groundwater levels drop.

6.5.6 Basin Scale Irrigation Recharge

Irrigation recharge is a component of the total recharge, but may not be accounted for in an estimate of aerial recharge. The key issues related to irrigation recharge in the Methow are:

a. Whether, at a basin or sub-basin scale, the total magnitude of irrigation recharge is a significant portion of the observed total recharge.

b. Whether, at a basin or sub-basin scale, irrigation recharge, the magnitude of irrigation recharge, relative to a natural, undisturbed watershed, is such that the location and timing of groundwater discharge to streams has been affected; and

c. Whether, at a local scale, flow paths originating from irrigation canals sustain in-stream (habitat) or out-of-stream uses.

Groundwater recharge resulting from irrigation practices is both common and well documented worldwide. It is not a unique issue to the Methow Basin. In the Pasco Basin of Washington, groundwater levels have increased as much as 500 feet since 1950 (Drost, 1993) in response to the development of the extensive irrigation system there. The scale of irrigation, relative to pre-irrigation water availability, is the principal factor determining the relative importance of irrigation to basin-scale groundwater recharge. In the Pasco Basin, pre-irrigation, “natural” groundwater recharge was estimated at about 42,000 AF/year. Current day groundwater recharge is 7 times greater than pre-irrigation levels, accounting for the large observed increases in water level. Over 40% of the increased recharge was attributed to canal seepage, with another 30% attributed to applied irrigation water. This magnitude of irrigation recharge in this example is significant, and has resulted in measurable changes in groundwater flow patterns relative to a natural state.

A discussion specific to the Methow is provided below and is based on the following assumptions:

- The irrigation season is 180 days long
- Cumulative irrigation diversions are 250 cfs (a total of 89,500 AF annually)

- Cumulative irrigation consumptive use is 150 cfs (a total of 53,500 AF annually)
- Cumulative irrigation canal losses are 100 cfs (a total of 35,700 AF annually)

In the Methow, the role of irrigation recharge on the system should be considered in terms of its annual contribution to the water balance and its potential seasonal contribution to the water balance. The long-term steady state effect of irrigation recharge is reflected in its magnitude relative to annual recharge. However, the seasonal effect of irrigation recharge in the basin is its return to the system as baseflow to the Methow River. Irrigation recharge is presented as a percent of annual recharge and a percent of current observed September baseflow below:

- **Percent of Annual Recharge.** The estimated current total annual recharge is on the order of 343,000 acre-feet, based on baseflow at Pateros. Using the return flow assumptions above, up to 35,700 AF of total irrigation recharge could be occurring in the Methow during one year. This is about 10% of the estimated current total annual recharge.
- **Percent of September Baseflow**. Mean September baseflow is on the order of 475 cfs at Pateros. This is the actual baseflow, not the regulatory baseflow. If irrigation canal losses have reached an equilibrium discharge rate of 100 cfs, then irrigation recharge could represent over 20% of the current mean September baseflow.

These examples indicate that the rate of irrigation recharge could be a significant proportion of the current observed rate of upwelling to the Methow mainstem and tributaries during late summer. The two key questions regarding the role of irrigation recharge on the Methow water balance are:

- **Is irrigation recharge actually present in the stream during the measured baseflow period (e.g. September)?** Streamflow hydrographs provide evidence that irrigation recharge is present in the Methow River as return flow during baseflow. The Chewuch river provides the best example. The Chewuch river hydrograph regularly “rebounds” when irrigation stops in October. The Chewuch is a geologically closed sub-basin, and all groundwater within the basin discharges above the USGS gage in Winthrop. Based on the last 10 years of data, the hydrograph rebound is typically on the order 40 cfs. Actual diversions over this period were on the order of 70 cfs. The difference between diversion and rebound (30 cfs) is canal loss, and the magnitude of rebound (40 cfs) is the “consumptive” loss (water that cannot be recorded at the gage). Canal loss therefore appears to be recharging the river at a rate of about 30 cfs at the time the ditches are shut down. If this were not the case, the magnitude of rebound would approach the total diversion rate. This rebound phenomenon is also observed in some of the hydrographs at Pateros. There are several examples of rebound effects on the order of 150 cfs, which is approximately equal to basin-wide consumptive use. Therefore, it appears that the total basin effect of irrigation recharge can be observed, and that most of the irrigation recharge is present as streamflow in the Methow River during September baseflow.

- **Do the current leaky irrigation systems "mitigate" for potential streamflow impacts associated with diversions?** In the absence of irrigation diversions, streamflows in the Methow system would be higher. Immediately below an irrigation diversion, streamflows are affected 1:1 by the irrigation diversion. The offsetting effects of irrigation return flows increase the further downstream from a diversion. At a basin scale, as described above the mitigating effects of leaky canals may be significant, but specific habitats could be affected and not mitigated depending on the location from the diversion point.

6.5.7 Local-Scale Irrigation Recharge

Irrigation recharge contributes to groundwater storage and subsequently to baseflow discharge incrementally along the length of the canal network. It is likely that stream-aquifer interactions that would occur naturally are either enhanced or reduced by a small percentage as a result of irrigation recharge. Locally, water levels near irrigation canals and the shallow flow paths from irrigation canals to discharge areas are affected by the presence or absence of water in the irrigation canal. The hydraulics of canal leakage are conceptually simple, but can be difficult to simulate numerically. This is because the leakage is affected by both saturated and unsaturated hydraulic properties. Numerical models, such as SEEP/W can accommodate saturated and unsaturated hydraulic conductivity functions, and therefore simulate seasonal canal leakage. In many cases, these types of simulations show that, during the initial cycles of a full and empty canal (when the underlying soil is completely dry), wetting fronts progress downward to the initial water table elevation, cause some groundwater mounding, and then return to the initial water table elevation. After several cycles of canal operation, residual soil moisture beneath the canal allows a more rapid and continuous hydraulic connection between the canal and underlying water table. This results in some residual mounding of groundwater levels directly adjacent to the canal, even when the canals are not full. So, conceptually, localized hydraulic effects may persist after cessation of canal operations.

From an ecological standpoint, the significance of local irrigation recharge is probably its potential influence on the hyporheic zone (the interface between ground water and surface water in the stream channel). Traditional concepts of groundwater flow are not entirely applicable in the hyporheic zone. In the hyporheic zone, the "aquifer" is effectively the stream channel itself and this "aquifer" is very dynamically linked to adjacent portions of the stream. Water quantity effects of irrigation (i.e. water volume in the hyporheic zone) will depend on very localized stream-aquifer relationships that cannot be characterized at a watershed scale. Chemical reactions that take place in the hyporheic zone are very important and influence the biogeochemical environment for aquatic ecosystems. The ability to understand this interface is challenging because it requires the focusing of different scientific and technical disciplines in a relatively small, restricted study zone.

6.5.8 Source of Water to Wells

Groundwater withdrawals modify the balance between recharge and discharge. Ecology convened a technical committee to investigate the scientific issues related to the capture of surface water by wells in 1998. The technical committee recognized that no single formula exists to evaluate the quantity, timing, location and duration of capture effects, and that there are numerous influences affecting the analysis of these effects. The committee recommended that the assessment of the source of water to wells be grouped into four classes:

- Water balance analysis, which simply identifies the outflow from wells relative to the inflow from recharge or other sources;
- Spatial analysis, which identifies the locations of capture, relative to the location of withdrawals;
- Timing analysis, which identifies when effects will occur relative to the onset of pumping; and
- Integrated numerical analysis, which integrates the water balance, spatial and timing analysis in a detailed model.

Detailed numerical techniques exist to simulate these aspects of groundwater flow, surface water interaction, and pumping responses. These numerical tools can and should be used for analysis at a local scale. However, for regional, basin scale watershed planning, conceptual representations of these processes are sufficient to identify management opportunities.

Groundwater rights have typically been evaluated in relation to the effects on a steady state water balance and/or spatial analysis. This reflects the “permanent” nature of water rights allocations, and requires the assumption that a year-round water right is used to its full extent all year long. More sophisticated water management strategies using conjunctive use (see next section) need to incorporate the effect of the timing of use.

Groundwater storage is the key concept in a timing analysis. When a well is pumped, water is initially withdrawn from the pore spaces in the aquifer, termed groundwater storage. As pumping progresses, the influence of the well begins to extend to hydraulic boundaries to the aquifer system, establishing equilibrium between recharge to and discharge from the aquifer system as a whole. During the initial period, water withdrawn from the well is predominantly groundwater storage and is not reflected as a reduction in discharge to surface water or an induced infiltration effect. Careful siting and operational management of seasonal pumping can significantly reduce (though not eliminate) the effects of groundwater withdrawals on streamflow in certain aquifer settings.

6.5.9 Conjunctive Use of Groundwater and Surface Water

The combined use of surface and ground waters to serve a particular purpose is commonly termed "conjunctive use." The term conjunctive use implies that there is a deliberate management goal or strategy for the source and use of the water at a given point in time. There are several opportunities for conjunctive use in the Methow, all centered around a general operating regime of using surface water when it is plentiful in the spring and early summer, and shifting to groundwater supply during the late summer and possibly during the winter, when surface water is less plentiful. The three key prerequisites for successful implementation of this strategy are:

1. The quantity and quality of the groundwater is adequate for the proposed uses;
2. The wells are sited such that they intercept deep regional flow paths rather than intermediate or shallow flow path in close hydraulic connection with the Methow River; and
3. The wells are operated to take maximum advantage from short-term aquifer storage and time lags.

Successful implementation of this strategy would result in “mining” a portion of groundwater storage. On a seasonal basis, this volume of storage would be recovered to a large extent during spring recharge. However, some residual effects are likely and, on an annual basis, a small portion of this storage could be reduced permanently. In a system with significant year-to-year fluctuations in recharge, however, the amount of storage reduction may be inconsequential relative to the magnitude of year-to-year variability. Aquifers in the mainstem Methow appear to be the best candidates for conjunctive use strategies. Aquifers in the Twisp and Chewuch sub-basins do not appear to be deep and large enough to take advantage of deep flow paths and groundwater storage effects.

Conjunctive use strategies could be applied to:

1. **Irrigation Water Supply.** Shifting irrigation supplies in the late summer from surface water diversions to groundwater wells could reduce the effect of diversions on late season streamflows. This may already occur to some extent, but it is unlikely that wells currently used as irrigation supply are sited to take maximum advantage of groundwater storage or deeper portions of aquifers. Recent well installations by WDOE for MVID show that high production wells with limited short-term hydraulic connection to the Methow River are feasible. The three wells are deep high capacity wells capable of producing 3,000 gpm (6.7 cfs) that intercept deep regional flow paths. When pumped seasonally, they will intercept deep down-valley flow and groundwater storage. An operational scenario of 90 days of pumping at 6.7 cfs would produce 1,200 AF of water. This amount is not likely to cause long-term declines in groundwater levels or streamflow because recharge (350,000 AF annually) greatly exceeds the annual amount pumped.
2. **Groundwater Augmentation of Streamflows**. An alternative to using groundwater as an irrigation supply would be to pump groundwater directly

into rivers to offset the effects of streamflow diversions. This is termed groundwater augmentation of streamflow. Depending on the location of the augmentation wells, streamflows could increase over what would occur naturally. The use of groundwater to maintain streamflows is not a new concept in the field of water resources management. The concept has been used in England since the mid-1970s. Currently, there are over 24 groundwater augmentation programs in England, provided over 5,000 cfs of flow to rivers from over 250 wells. Groundwater augmentation could be used in two ways:

- It could be applied in a downstream location to offset impacts from upstream diversions. In this case, it is replacing water that is diverted upstream.
- It could be applied in an upstream location and withdrawn as a downstream surface water diversion. In this case, it is adding water that would not otherwise be in the stream, allowing for downstream withdrawal without impact.

Since the water is put directly into the stream, the effects of hydraulic continuity are reduced, so groundwater augmentation may provide better management of the water balance.

3. Irrigation Recharge. Current irrigation practices are an example of conjunctive use, though inadvertent. The diversion and application of water taken during periods of high run off shifts the timing of streamflows slightly, causing water that would otherwise stay in the stream during peak flows to return at a slower rate via groundwater. The current canal system distributes canal losses over large areas, and it is difficult to quantify and characterize effects. Targeted infiltration of peak flows could augment streamflows in specific areas.
4. Aquifer storage and recovery (ASR) is a specialized form of conjunctive use that involves artificially recharging an aquifer with excess surface water and withdrawing this water at a later date via groundwater wells. ASR has been applied in confined or lower permeability aquifer systems with depressed water tables, where the aquifer acts very much like a storage reservoir. ASR has also been applied in aquifer systems with poor water quality and low hydraulic gradients, where the injected water creates a "bubble" of better quality water that is withdrawn after a short residence time. ASR is not considered feasible for the alluvial aquifers in the Methow because the aquifers do not meet the typical criteria for ASR systems. Bedrock may be a suitable ASR reservoir and could be considered for further study. This would require geologic characterization and hydraulic testing.

TABLE 6-1

Primary Groundwater Parameters in Each Sub-Basin

	Sub-Basin	**Upper Methow[2]**	**Chewuch[5]**	**Middle Methow[5]**	**Twisp[4]**	**Lower Methow[3]**	**Total**
Basic Data	**Aerial aquifer extent (acres)[1]**	10,000	5,200	6,000	5,000	20,000	26,200
	Average aquifer width (ft)[1]	10,000	6,000	8,000	3,000	8,250	NA
	Average saturated thickness(ft)	800	150	200	150	200	NA
	Aquifer Volume (Acre-ft)	8,000,000	780,000	1,200,000	750,000	4,000,000	**10,730,000**
	Transmissivity (ft2/day)	140,000	40,000	60,000	40,000	60,000	NA
	Hydraulic conductivity (ft/day)	175	267	300	267	300	NA
	Porosity (dimsensionless)[5]	0.3	0.2	0.2	0.2	0.2	NA
	Hydraulic gradient (ft/mile)[5]	30	40	30	40	30	NA
	Calculated downvalley groundwater flow rate (cfs)[6]	92	21	32	11	33	NA
	Calculated groundwater storage capacity (AF)[7]	2,400,000	156,000	240,000	150,000	800,000	**2,946,000**
Aerial Recharge Estimate	**Estimated Annual WL Fluctuation (ft)[5]**	22	15	20	7	6	NA
	Estimated annual recharge based on WL Fluctuation (AF)[8]	66,000	15,600	24,000	7,000	24,000	**112,600**
	Calculated annual downvalley groundwater flow (AF)[6]	66,653	15,235	22,852	7,617	23,567	**112,358**
Total Recharge Estimate	**Reporting Streamgage**	Methow at Winthrop	Chewuch at Winthrop	Methow at Twisp	Twisp at Twisp	Methow at Pateros	
	Estimated Mean September Baseflow Discharge (cfs)[9]	271	71	286	47	474	
	Downvalley Flow as % Baseflow Discharge	34%	30%	51%	22%	39%	
	Estimated Annual Recharge based on mean September Baseflow (AF)	196,195	51,402	207,055	34,026	343,160	**343,160**

Footnotes

Data Sources

[1] GIS Coverages

[2] EMCON, 1993. Draft Upper Methow Groundwater Management Hydrogeological Summary Report

[3] HWA Geosciences, 2001. Aquifer Testing and Hydrogeological Evaluation, Methow Valley Irrigation District

[4] Montgomery Water Group, 1996. Methow Valley Irrigation District Water Supply Facility Plan

[5] Estimate based on Professional Judgement

Calculations

[6] Downvalley Flow Rate = Aquifer Transmissivity x Aquifer Width x Hydraulic Gradient

[7] Groundwater Storage Capacity = Aquifer Area x Aquifer Thickness x Porosity

[8] Annual Recharge = Annual WL Fluctuation x Aquifer Area x Porosity

[9] Annual Rechage = Baseflow discharge using hydrograph separation (Ecology, 1999)

Monthly Average Baseflow Characteristics

Station No.	Station_Name	Month	October	November	December	January	February	March	April	May	June	July	August	September
12447383	METHOW RIVER ABOVE GOAT CR NEAR MAZAMA, WA.	Mean Baseflow (ft3/sec)	5.2	33	33	15	12	*	*	*	*	*	169	37
		Mean Streamflow (ft3/sec)	8.1	72	90	21	17	150	634	2150	2080	917	195	44
		Mean Baseflow as a % of Total Streamflow	64	46	37	73	69	*	*	*	*	*	86	84
12447390	ANDREWS CREEK NEAR MAZAMA, WA.	Mean Baseflow (ft3/sec)	6.2	5.7	4.7	3.9	3.5	*	*	*	*	*	13	7.8
		Mean Streamflow (ft3/sec)	6.8	6.2	4.8	4	3.6	3.8	15	115	155	45	14	8.7
		Mean Baseflow as a % of Total Streamflow	92	92	97	95	98	*	*	*	*	*	93	90
12448000	CHEWUCH RIVER AT WINTHROP, WA.	Mean Baseflow (ft3/sec)	82	76	70	61	65	*	*	*	*	*	149	71
		Mean Streamflow (ft3/sec)	90	84	80	67	72	116	432	1570	1550	516	170	81
		Mean Baseflow as a % of Total Streamflow	90	90	88	92	91	*	*	*	*	*	88	87
12448500	METHOW RIVER AT WINTHROP, WA.	Mean Baseflow (ft3/sec)	248	300	290	238	244	*	*	*	*	*	484	271
		Mean Streamflow (ft3/sec)	260	396	353	253	257	471	1460	4450	4640	1610	543	288
		Mean Baseflow as a % of Total Streamflow	95	76	82	94	95	*	*	*	*	*	89	94

TABLE 6-2

Monthly Average Baseflow Characteristics

Station No.	Station_Name	Month	October	November	December	January	February	March	April	May	June	July	August	September
12448998	TWISP RIVER NEAR TWISP, WA.	Mean Baseflow (ft3/sec)	54	73	75	64	72	*	*	*	*	*	100	47
		Mean Streamflow (ft3/sec)	61	113	109	70	77	128	351	849	925	428	108	53
		Mean Baseflow as a % of Total Streamflow	88	64	69	90	93	*	*	*	*	*	93	88
12449500	METHOW RIVER AT TWISP, WA.	Mean Baseflow (ft3/sec)	378	408	346	286	291	*	*	*	*	*	462	286
		Mean Streamflow (ft3/sec)	424	471	406	314	322	441	1600	5080	4920	1740	493	311
		Mean Baseflow as a % of Total Streamflow	89	87	85	91	90	*	*	*	*	*	94	92
12449950	METHOW RIVER NR PATEROS, WA.	Mean Baseflow (ft3/sec)	441	457	393	369	388	*	*	*	*	*	655	418
		Mean Streamflow (ft3/sec)	487	535	483	427	425	615	1590	5060	5950	2150	699	453
		Mean Baseflow as a % of Total Streamflow	91	85	82	86	91	*	*	*	*	*	94	92
12450500	METHOW RIVER AT PATEROS, WA.	Mean Baseflow (ft3/sec)	501	505	419	366	362	*	*	*	*	*	702	474
		Mean Streamflow (ft3/sec)	532	545	457	396	381	538	1850	4860	6050	2530	743	505
		Mean Baseflow as a % of Total Streamflow	94	93	92	92	95	*	*	*	*	*	95	94

Source: Baseflow Characteristics of Washington River and Streams, WDOE Pub No. 60 Oct., 1999.

* Baseflow not calculated