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Walla Walla Basin Watershed Council
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# Aquifer Recharge as a Water Management Tool: Hudson Bay Recharge Testing Site Report (2004-9)

*HBDIC Recharge Project Expansion with Basin #1 (foreground), spring 2008*

April 18th, 2010

<u>Prepared by</u>

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For

**Hudson Bay District Improvement Company (HBDIC)**

In Support of

OWRD Limited Testing License (Final Order #1059)
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# 45 Years Ago…

*"Some initial tests at artificially recharging the gravel aquifers by placing excess surface water into gravel pits and onto unused gravelly fields have reportedly helped raise temporarily the water level in wells of their vicinities. A comprehensive plan for the systematic management of the old gravel as a water reservoir is an obvious need that will surely come about ultimately. Such a comprehensive plan and systematic management will need to include all phases of natural and artificial recharge in order to obtain maximum benefits from this important natural water-storage facility."*

**Geology and Groundwater Resources of the Walla Walla River Basin, Washington-Oregon.**

**Robert Newcomb, USGS - 1965**

*"What you have to do and the way you have to do it is incredibly simple. Whether you are willing to do it is another matter."* ***(Peter F. Drucker)***

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**Dedicated to the citizens, water users and salmon recovery advocates of the Walla Walla Basin**. Without the "can-do" spirit of the people of the Walla Walla River valley, none of this would have been possible.

# Executive Summary

The Walla Walla Basin is a bi-state basin in northeastern Oregon and southeastern Washington, through which flows the Walla Walla River. The Walla Walla River, and its tributaries, originate in the Blue Mountains, and generally flow westward to a confluence with the Columbia River near Wallula Gap. The river system itself is a primary passage and rearing habitat for ESA-listed steelhead and bull trout, and a focus of tribal efforts at Chinook salmon and lamprey restoration. In addition, the portion of the Walla Walla River system which lies within the Walla Walla Basin and is the focus of this report overlies an alluvial aquifer system that displays a high degree of hydraulic continuity with the River. In the past 50 to 60 years a large number of wells (large and small) have been drilled into, and extract water from, this alluvial aquifer system.

This report:

1. Describes the basic hydrologic conditions that have developed in the Walla Walla Basin in response to development of basin water resources.
2. Looks more closely at alluvial aquifer system conditions that have developed – including a history of water level decline and the possible impacts these declines have had on streams and springs
3. Describes the results of six seasons of shallow aquifer recharge (SAR) activity at the Hudson Bay site.

***The Setting:*** Alluvial sediments (clay, silt, sand, and gravel) largely derived from the adjacent Blue Mountains fills the Walla Walla Basin to a depth of 800 feet in some places. These strata filled a basin that formed as the basalt bedrock that underlies the region was down-dropped by a series of folds and faults that formed in response to regional tectonic stresses. As this bedrock dropped, sediments washed off the Blue Mountains by the ancestral Walla Walla River and other streams collected in the subsiding basin.

Prior to the advent of widespread diversion of surface water and groundwater for agricultural irrigation, industrial uses (primarily food processing), stock watering, and domestic and municipal water supply the Walla Walla Basin was crossed by a series of streams that drained off the Blue Mountains. Most of these streams flowed year round. In addition, as a result of seasonal snow melt and flooding these streams recharged an aquifer system hosted by the alluvial sediments filling the Basin. One of the manifestations of that recharge was the presence of numerous springs on the valley floor. These springs showed the locations where the aquifer system, once fed by seasonally flooding and recharge, discharged to surface waters providing base-flow for streams. In another sense, the abundant springs and streams demonstrated that the alluvial aquifer system was full, and had achieved an equilibrium that balanced recharge with discharge. With the advent of permanent settlement, irrigated farming, and the development of supporting industry, the hydrology of the basin was changed.

***Changing Hydrologic Conditions:*** In the years following the establishment of the Whitman Mission, Fort Walla Walla, and the towns that now dot the Walla Walla Basin landscape, natural streams tributary to the Walla Walla River, and the Walla Walla River itself, have been straightened and channelized to facilitate the delivery of irrigation water and reduce the extent of seasonal flooding. Stream channel straightening, coupled with the draining of wetlands and boggy areas has increased cropped acreage, pasture availability, and rural residential home building sites. In recent years, un-lined ditches have been replaced by lined ditches and pipes to reduce water conveyance losses and withdrawals from the Wall Walla River. In addition, the primary irrigation districts active in the Basin have reduced the period of time during which they divert water from the Walla Walla River.

All of these actions resulted in the loss of alluvial aquifer recharge; as the residence time and spreading of surface water in the basin was reduced. These actions also likely facilitated a decline in alluvial aquifer water level as channel straightening led to channel deepening; this in turn led to declines in aquifer base level. With alluvial aquifer water level declines, stream flows were further impacted as base-flow and spring-flow was lost. Coupled with these changes to the surface hydrology has been a parallel increase in the number of wells extracting water from the alluvial aquifer system. The impact of these factors on Walla Walla Basin hydrology includes reduced river flow, a flashy river system, and declines in aquifer levels and corresponding base-flows, coupled with diminished aquifer storage.

Recognizing these trends, the Walla Walla Basin Watershed Council (WWBWC) in partnership with the Hudson Bay District Improvement Company (HBDIC) decided in 2003 and 2004 to build a pilot alluvial aquifer recharge project. The goals of this project are to test the feasibility of SAR, develop operational and monitoring plans that can be used to facilitate future SAR projects. Most importantly, the project aims to recharge the alluvial aquifer to the extent possible given the physical constraints of the recharge site and the surrounding aquifer system. Recharge operations have been conducted at the HBDIC SAR site in the winter and spring of each of the past 6 years, or seasons.

***The HBDIC SAR Project:*** Construction and recharge operations at the Site began in the late winter and spring of 2004. At that time 3 infiltration basins, totaling 0.34 acres in size, were constructed adjacent to the HBDIC's White Ditch. The White Ditch delivers Walla Walla River water to the Site. Site recharge operations began in March 2004 after receiving Oregon Water Resources Department Limited License LL-758. This license permitted SAR at the site under OWRD's aquifer recharge rules, and includes:

1. Groundwater and source water monitoring requirements.
2. Stipulations on Site operation related to flows that can be delivered to the Site and minimum flows required in the Walla Walla River (the source of water for the project) to allow the project to operate.
3. The length of each recharge season, November 1st through the following May 15th.
4. Reporting criteria and requirements.

The license was granted following review and comment by other affected entities, including the Confederated Tribes of the Umatilla Indian Reservation and Oregon Department of Environmental Quality.

During the second season of operation, the 2004-2005 recharge season, the infiltration basins were increased in size, to a total area of 1.1 acres. A fourth basin was added during the 2007-2008 recharge season, increasing the total size of the infiltration basins to 1.4 acres. The original limited license expired in February 2009. In lieu of an application for a permanent water right to operate the HBDIC SAR project, a second limited license (LL#1059) was granted to the project that extended the operational schedule to the summer of 2013. During the 2008-2009 recharge season, all four infiltration basins plus a series of four infiltration galleries were operated.

Through the course of the six recharge seasons completed to-date, the site was operated for a total of 602 days. During this time, approximately 13,100 acre-feet of water was discharged to the underlying alluvial aquifer system. Recharge volumes ranged from a low of approximately 400 acre-feet during the first recharge season, 36 days in the spring of 2004, to a high of 3200 acre-feet in the 128 day long 2006-2007 recharge season. The HBDIC SAR project is interpreted to have had a beneficial impact on the surrounding area, including restoration of flow from the springs that feed Johnson Creek and increased water levels seen in wells in the vicinity of the Site. The fact that long-term water level declines appear to have been slowed, or even reversed in wells in the area of the project suggest that SAR has the potential to both increase water levels in the alluvial aquifer and replace water lost to pumping (increase storage). Groundwater quality also has been shown to have not been degraded as a result of the project.

***Conclusions:*** Our basic conclusion is that the HBDIC SAR project shows that this type of activity is a viable option for water resource managers in the Walla Walla Basin. SAR recharges the aquifer in areas where natural recharge mechanisms have been lost. As long as good quality water is used, such as is naturally flowing into the Basin via the Walla Walla River, alluvial aquifer degradation is not expected to occur. Selectively locating SAR sites across the Basin has the potential to help water managers replenish depleted groundwater supplies and provide clean, cold base-flow to streams and springs at critical times. Some challenges for future SAR projects will be finding locations that allow water managers to meet such goals and acquiring a source of water to use for SAR.

# PART I. BACKGROUND

## Forward

Water remains at the center of nearly all the current natural resource restoration efforts in the bi-state Walla Walla Basin. The State of Oregon has designated beneficial uses[1] for water in the Walla Walla Basin's to include fish and aquatic life, wildlife, domestic supply, irrigation, livestock, industrial, boating, recreation and for its aesthetic qualities (**Figure** 1). The water needs have changed over the years and now the pressure has increased to find water to ensure all beneficial uses are supplied and maintained. Like many watersheds across the arid western United States, water managers and watershed planning groups struggle to find solutions to the water supply – demand balance. In the Walla Walla Basin, there has been increasing interest in the capture and storage of surplus wet season (winter/spring) water for use during the times when supply is at a deficit. Currently there are a number of groups working to design tools for aquifer management, including: building small and large scale surface-storage reservoirs, a Columbia River pumping exchange projects, a water banking system for surface and groundwater rights, and as this document details the use of managed aquifer recharge for subsurface-storage.

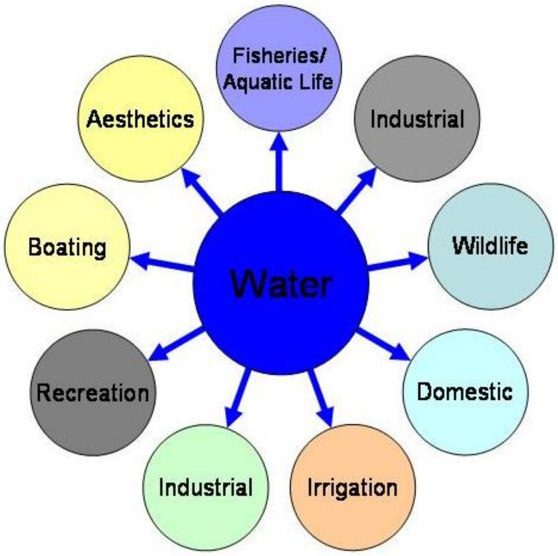

**Figure 1. State of Oregon Beneficial Waters Uses for the Walla Walla Basin.**

The main purposes of this report are to provide an introduction to managed aquifer recharge (MAR) as a water management tool, the water management needs it targets and provide a report on the design, operation, monitoring and analysis conducted at the basin's largest recharge site, the HBDIC Recharge Site from 2004-9.

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[1] OAR 340-04-0330 Table 330A. Online at: http://www.deq.state.or.us/standards/WQstdsFinalGenBenUseTables.htm

Managed aquifer recharge and the use of natural landforms or features to store water are in concert with the WWBWC' community-based mission:

> *"Protect the resources of the Walla Walla Watershed, deal with issues in advance of resource degradation, and enhance the overall health of the watershed, while also protecting, as far as possible, the welfare, customs, and cultures of all citizens residing in the basin." (WWBWC, 2003)*

The community's exploration of MAR demonstrates the emerging appreciation that real solutions to water resource challenges of the future are non-simplistic (e.g. pipe water here, save it there) and cannot be solved by trying to isolate interconnected parts into unilateral solutions. As water continues to be an issue of varying political views it is important to clearly state the perspective from which this report is written with assumptions being:

1. The Little Walla Walla River system was historically and is currently an important part of the management of the basin's surface and subsurface water resources; particularly as they relate to flow in the Walla Walla River mainstem.
2. The historic springs that rely on the shallow aquifer are worthy of protection and restoration, and they serve critical physical and biological roles in the health of the watershed system.
3. Solutions to our water management issues will only be achievable if surface and groundwater is managed conjunctively into the future.

To define the occurrence of water in the shallow aquifer, it is easiest first to discuss the aquifer as it relates to the watersheds overall water balance. For all practical purposes we can treat the water balance of the Walla Walla watershed as a closed system, meaning there are no significant external inflows or outflows of groundwater. However it should be clarified for the purposes of this discussion that an aquifer's storage is always changing due to time related events ranging in minutes to years. Storage can change due to rainfall, spring river freshets, irrigation season well pumping and a long list of other hydrologic events. But when you view this system on a longer timeline for the purpose of managing the resource for future use, this is when trends in storage can be effectively assessed. The general water balance is:

$$P = Q + E + \Delta S_S + \Delta S_G$$

**Equation 1 Watershed Water Balance (budget) Equation (Freeze, 1979)**

Where **P** represents all the precipitation that falls on the watershed, **Q** (discharge) represents all the flow that leaves the watershed via the surface, ***E*** as the total evapotranspiration, or the sum of all evaporation and plant transpiration, $\Delta S_S$ as the change in storage of the surface-water reservoir and $\Delta S_G$ representing the change in storage of the groundwater reservoir. The value for $\Delta S_G$ or change in groundwater storage is dictated by the balance between what is recharged to how much is discharged from the confined and unconfined aquifers of the basin. For the purposes of this discussion, we focus on only the changes that influence the balance of groundwater storage in the shallow aquifer system.

Conceptually the shallow aquifer $\Delta \mathbf{S_G}$ can be seen as dependent on the net balance between inputs (recharge) and outputs (discharge). The physical mechanisms that induce infiltration or recharge to groundwater storage ($\mathbf{S_G}$) come in a variety of forms including precipitation, channel bed losses from streams, rivers and ditches, and the application of irrigation water such as flood, rill or sprinklers. Mechanisms by which groundwater storage ($\mathbf{S_G}$) is lost or discharged include well pumping, groundwater seepage directly to channel beds and springs and seeps, and the evapotranspiration of water though agricultural vegetation with roots that extract water directly from the aquifer's water table (**Figure** 2).

4.

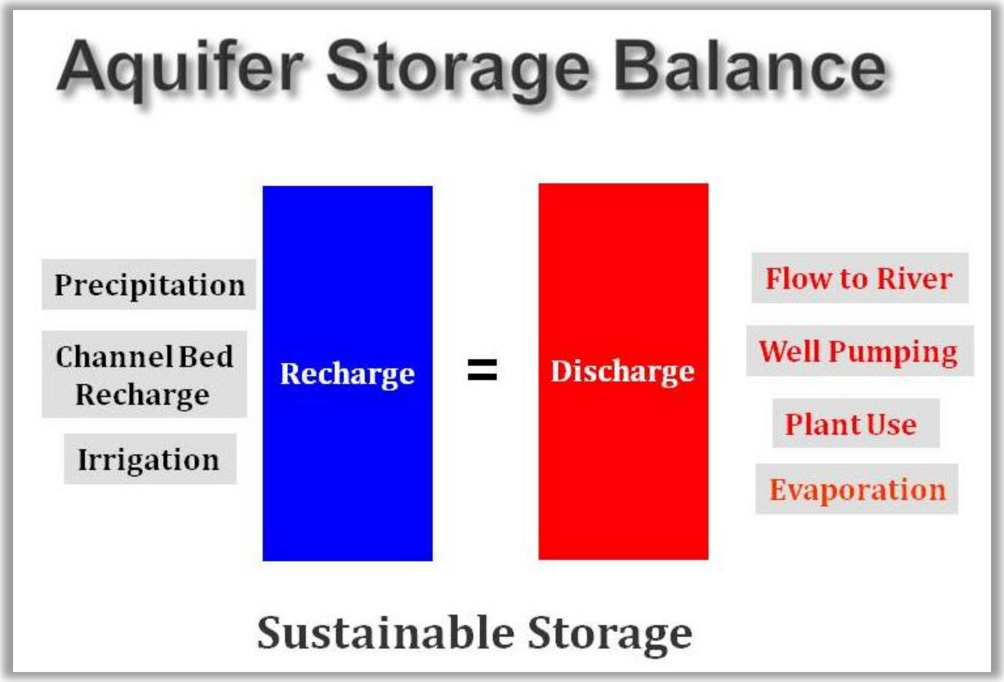

**Figure 2. Mechanisms that influence balance of shallow aquifer storage (WWBWC, 2007)**

We define an aquifer' storage as balanced or *sustainable* when the net quantity and timing[2] of recharged water is equal relative to net quantity and timing of discharge water (**Figure** 3). A system is out of balance when storage is either increasing or decreasing.

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[2] For the purposes of this introductory to recharge, a steady-state water balance was assumed.

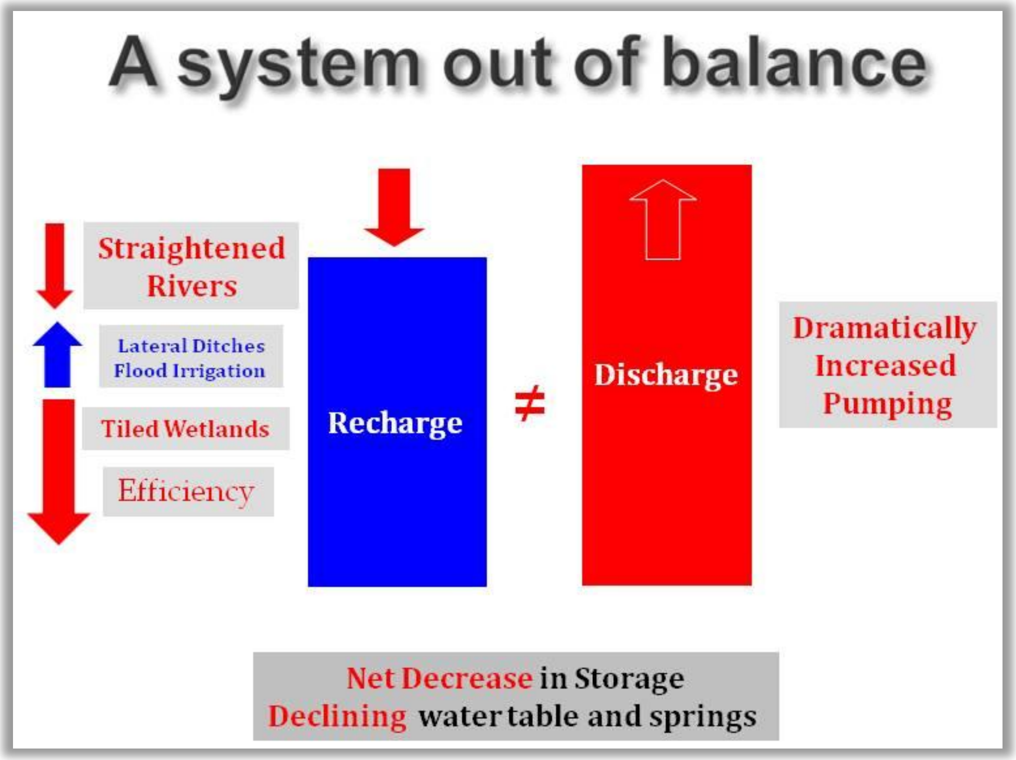

**Figure 3. Historical changes propagating the status of shallow aquifer storage balance ($\Delta S_G$)**

## Basin Overview and Development of Managed Aquifer Recharge

The Walla Walla basin is located in Northeastern Oregon and Southeastern Washington (**Figure** 4). This bi-state system's primary water supply comes from the Walla Walla River which originates in the Blue Mountains of Oregon and flows down through Washington to the Columbia River near Wallula Gap. This river system is the Walla Walla watershed's primary passage and rearing corridor for ESA-listed steelhead and bull trout, and species of tribal cultural significance including chinook salmon and lamprey. In addition, it also serves as the main recharge source for the underlying shallow aquifer system. The Walla Walla River also has had two EPA required Total Maximum Daily Load (TMDL) assessments for nonpoint source pollution which were completed in Oregon (ODEQ-WWBWC) for temperature and in Washington (WDOE) for soluble organic compounds, temperature and sediment.

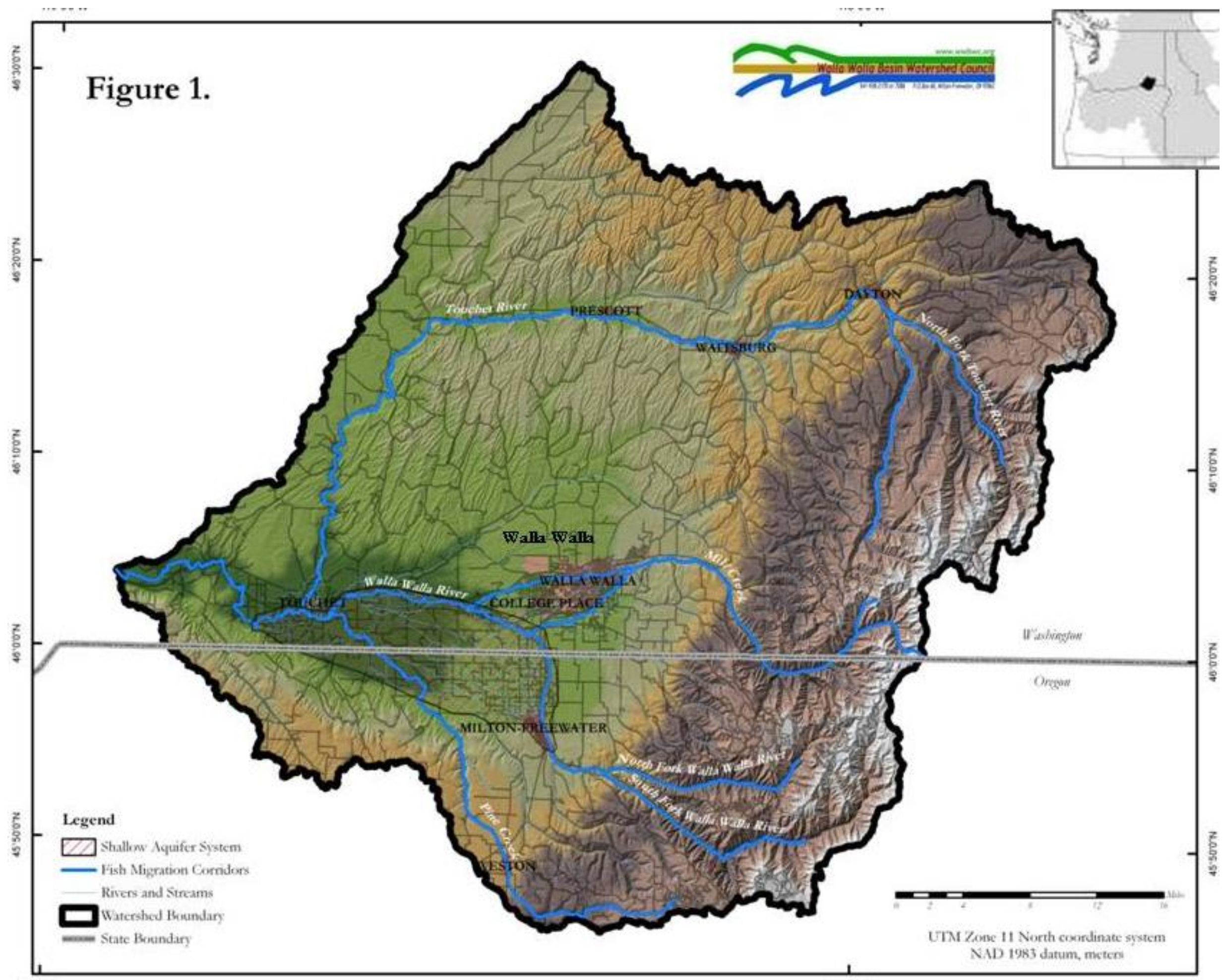

**Figure 4 Map of the Walla Walla Basin Watershed (Baker T. , 2010)**

The area this report focuses on is the Walla Walla River Valley subbasin.[3] In this subbasin the Walla Walla River historically exited the highlands bordering the basin, at which point it branched into a system of distributary channels that flowed out across the valley floor. These channels then recombined into a single main channel in the central portion of the valley (**Figure** 5). Within this branched distributary stream system groundwater fed spring-creeks were common. With agricultural development, many of these distributary branches were converted to and connected by, irrigation water delivery ditches and connecting lateral ditches.

Newcomb (1965), and even before him Piper (1933) provided a very compelling argument that showed the distributary and spring system was created and maintained over the top of an unconfined alluvial aquifer system. This aquifer supplies the baseflow for more than 50 valley spring-creeks in Oregon and Washington that historically provided year-round baseflow in the form of cool groundwater and off-channel habitat to the mainstem (**Figure** 6). The 240 square-mile

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[3] 2006-2010 Development of a Surface-groundwater model to use as a flow restoration and aquifer replenishment planning and management tool.

aquifer also provides direct groundwater contributions in channel to the mainstem Walla Walla River which is particularly important during the summer irrigation and fisheries rearing and passage season. With historically braided and meandering channels and native beaver populations helping to pond and slow water down, the Walla Walla or as the Cayuse Tribe named this subbasin the “*land of many small waters*” historically supported a thriving salmon fisheries and miles of distributary habitat.

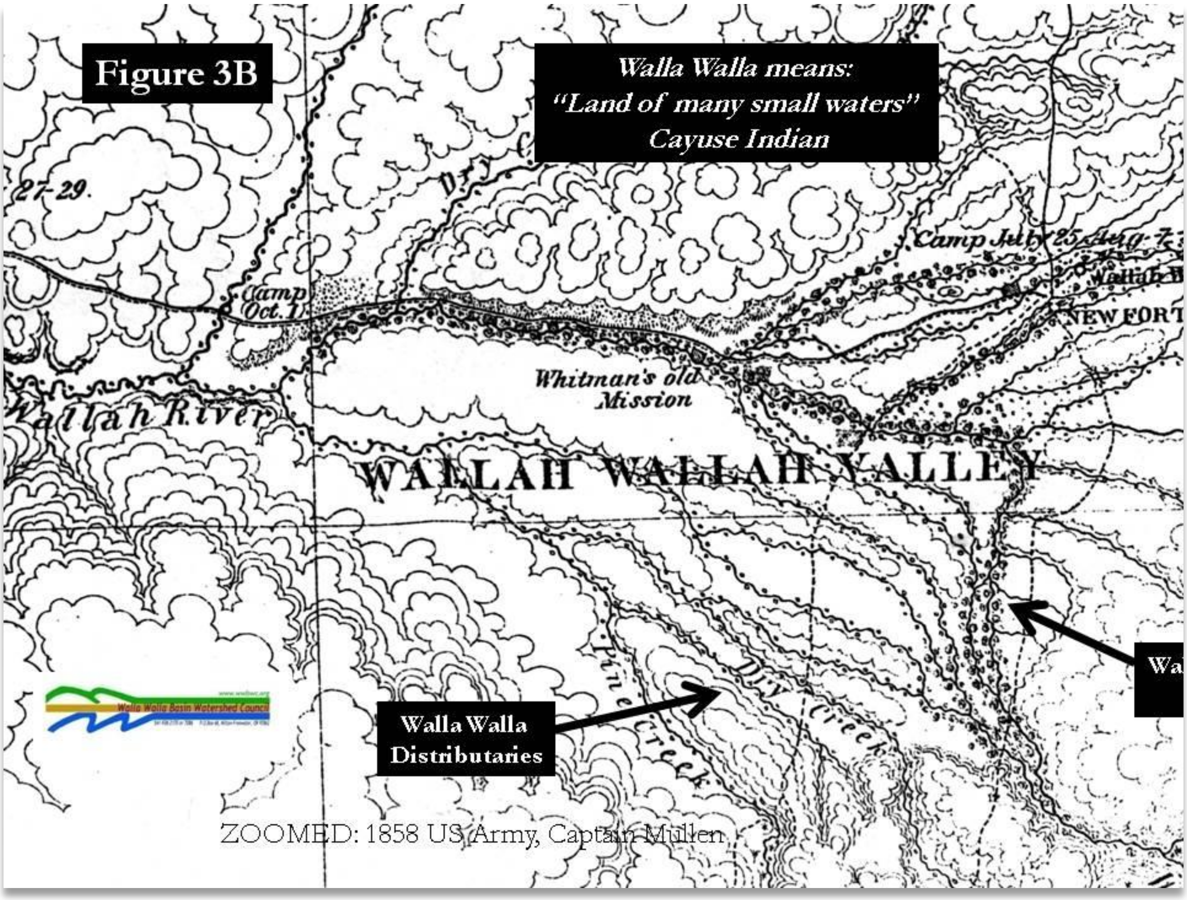

**Figure 5. 1858 Mullen Map of Distributary Walla Walla and Little Walla Walla River System (Mullan, 1863)**

With the onset of irrigated agriculture, the way in which water was redistributed and used began to change the hydrologic balance of this system. Naturally meandering rivers and creeks were straightened for flood control and irrigation water delivery, acting indirectly to speed up the flow of water through the system. This was offset to a degree by the valley’s early flood and rill irrigation practices and the development of the lateral ditch system that acted to effectively ‘slow’ surface run-off. By redirecting surface waters away from the primary natural flow corridors, such activities were acting to unintentionally help recharge the underlying shallow aquifer system.

Coupled with these changes to the aquifer's ability to be replenished (recharged) there were subsequent dramatic increases in groundwater use**.** The dramatic increase in the number of wells for primary and supplemental irrigation rights acted to increase the amount of water coming out of groundwater storage. The net hydrologic impact of these changes was an aquifer-spring system that experienced reduced storage, as recharge was decreased and discharge was increased; creating an overall decline in storage that has manifested itself in a declining water table and the drying up of natural spring flows.

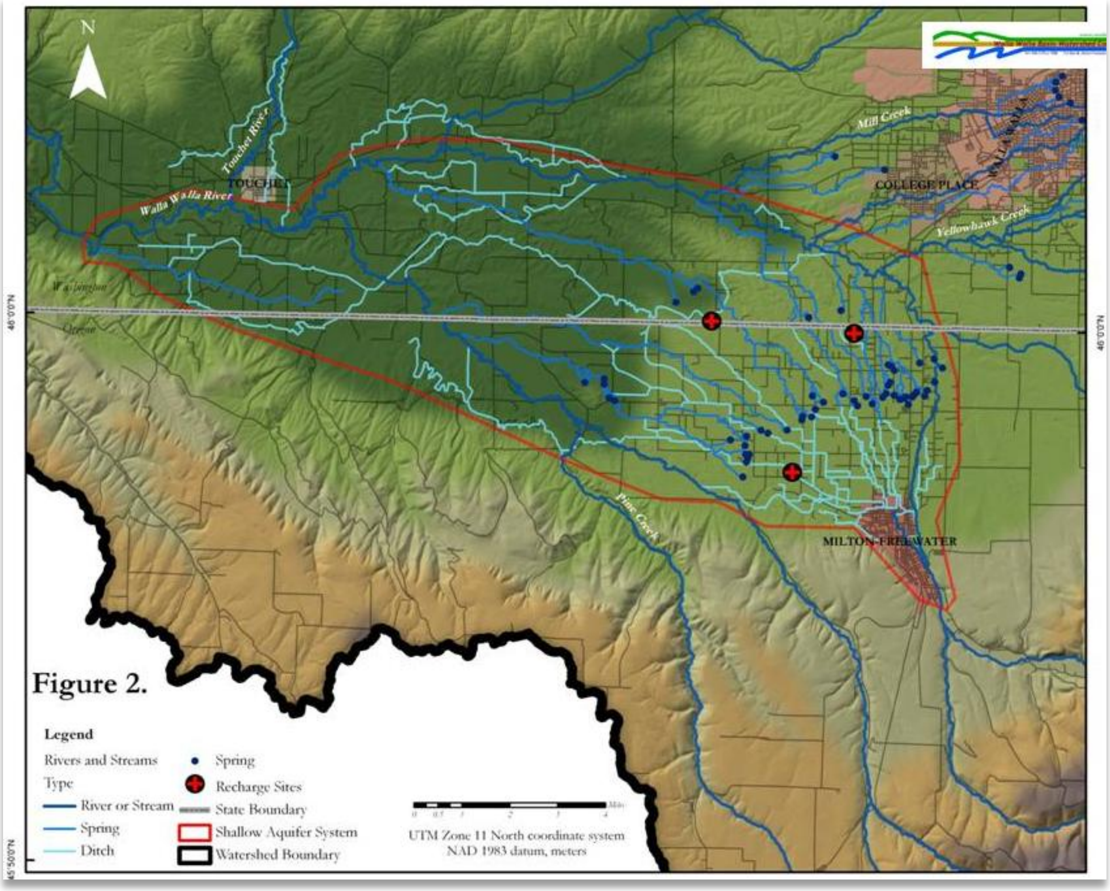

**Figure 6. Bi-state Walla Walla and Little Walla Walla River System Area including Aquifer Recharge Testing (WWBWC)**

While this surface to groundwater connection was first outlined by the USGS in 1933 (Piper, 1933) and again in 1965 (Newcomb, 1965) it was not revisited until the summer of 2000 that the community was forced to reexamine the situation. Starting with the ESA listing in 1998 and the *American Rivers* listing of the Walla Walla River on the top-10 most endangered rivers list in 2000, federal fish agencies worked out an agreement with the three larger irrigation districts to divert less water to these distributary branches and ditches and leave more in the 'mainstem' Walla Walla

River. This agreement re-watered an Oregon section of the river with 1/3 of the volume that had previously been diverted to irrigation during critically low summer-time base flows and was heralded nationally as a model of cooperation. However these dramatic changes in water management in the Little Walla Walla river system along with the piping of leaky ditches to stretch less water further had both immediate and longer term consequences. The springs that had been providing some baseflow (although not at historical potential) back to the Walla Walla River dramatically declined to the point that by 2009 many are nearly dry year round.

Through a series of public and WWBWC meetings, the WWBWC and its partners began to examine the historic conditions of these streams and their connection to the underlying alluvial aquifer; which they depend on for baseflow. Starting in 2001, the WWBWC and partners started developing a monitoring network and series of on-the-ground aquifer recharge projects designed to address these water management challenges. With the development of the Bi-state Watershed Management Initiative (WMI) Monitoring Program (2005 – present) a monitoring network currently comprising of over 110 wells and 50 stream flow gauges has been developed to monitor 'pre' and 'post' flow restoration conditions and provides the basis on which to build a programmatic solution**.** This program also funded a number of other technical activities from which to base the development of this program including: stratigraphy maps of the alluvial aquifer**,** a finite-element surface-groundwater numerical model (OSU) and various other field projects that help characterize the extent and properties of the shallow aquifer system.

Three main recharge projects have provided the basis upon which the WWBWC and its partners are now developing the Aquifer Replenishment and Spring Restoration (ARSR) Program (See Moving Forward Section)**.** The Hudson Bay District Improvement Company's (HBDIC) aquifer recharge project was the first of its kind in Oregon and Washington in both its physical design and its water quality monitoring plan (co-developed with ODEQ and OWRD staff). The HBDIC recharge project site, a 7-acre area Northwest of Milton-Freewater, is entering the final phase of its three part expansion under this program. The two other recharge testing projects funded by Washington's Department of Ecology include one testing field flooding[4] as a mechanism for aquifer recharge with the other using a historic gravel pit to recharge winter-spring water into groundwater storage. All of the sites have been providing detailed information on the designs, operations, monitoring and permitting-planning needs to implement aquifer recharge in the Walla Walla Basin.

## Historical Trends in Walla Walla Basin Aquifer Hydrology and Hydrogeology Leading to Managed Aquifer Recharge

Generally the Walla Walla River, its tributaries, its distributaries and the shallow gravel aquifer they pass over are interpreted to be highly interconnected. Water moves relatively easily between ditches, streams, rivers and the shallow alluvial aquifer because of the highly permeable nature of gravel streambed channels so common across the Basin, and the gravelly character of the underlying alluvial aquifer system. Depending on the spatial variation in these streambed and aquifer conditions, the

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[4] Hall-Wentland farm fields and the Locher Road historic gravel pit

degree of hydraulic connection between surface water and groundwater and the location of gaining and losing stream reaches generally can be defined by the depth to groundwater.

A survey of historical data shows changes in alluvial aquifer groundwater levels over time. WWBWC staff reviewed the existing data collected by Oregon Water Resources Department (OWRD) staff at historic observation wells originally set up by the United States Geological Survey (USGS). A total of 11 state observation wells (SOWs) that monitor the shallow, unconfined alluvial aquifer system were reviewed for trend information (**Figure** 7. Reviewing the data from the SOWs showed that all eleven wells display a downward trending water table with three (SOW # 844, 845, 857[5]) now having gone completely dry.

Taking a closer look at data from the OWRD SOW wells, SOW #850 shows approximately a 5 feet decline between 1940 and 2005 (**Figure** 8). The aquifer decline at this location is particularly

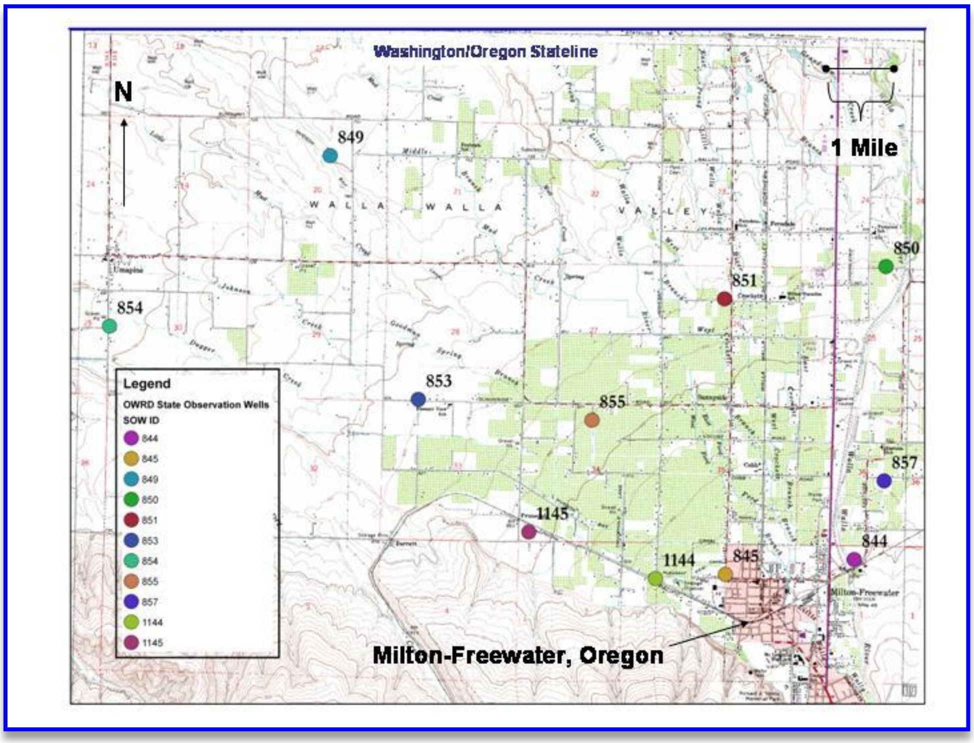

**Figure 7. Site Map for Oregon Water Resources' State Observation Wells (1933 to present)**

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[5] SOWs 844 and 845 have since been abandoned and backfilled due to lack of water to measure and posed a safe hazard.

Historical Static Level GW-20 G Ransom (OWRD SOW well: 1949 to 2005)

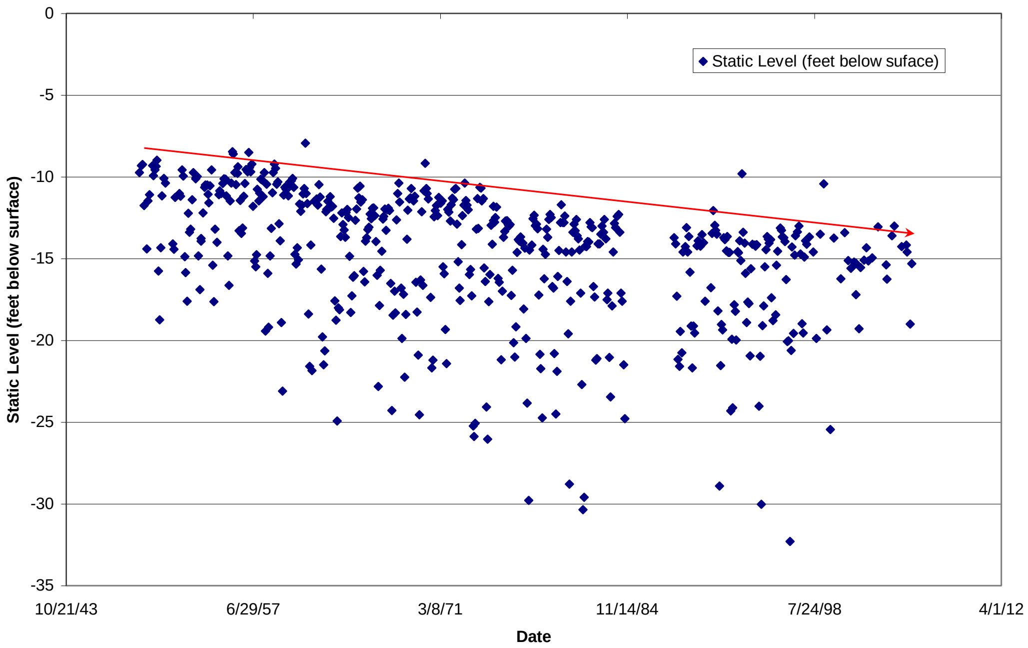

**Figure 8. Depicting drop in aquifer at observation well next to Walla Walla River.**

alarming because it is in an area near the Walla Walla River channel where considerable flow losses to the aquifer through the porous channel bottom is known to occur. Therefore, even with a steady source of recharge water available, aquifer level appears to be declining. This well location also sits on the geologic arc or contour of the 'inner zone springs'. Consequently, water level changes seen in it may provide insights into conditions expected within this zone of springs.

The well with one of the longer periods of record is SOW #853 (McKnight Well). It is located approximately 3 miles west, and down gradient from the Walla Walla River and Little Walla Walla River distributary system (**Figures** 7 and 9). The primary sources of recharge for this well generally are thought to include seepage from the Walla Walla River, the Little Walla Walla River, irrigation ditches and flood irrigation. This well demonstrates a characteristic found in nearly all of the historically hand-dug wells[6] in the Walla Walla River valley; alluvial aquifer water levels have dropped below the base of the well which was once productively producing water from the upper few feet of that aquifer. By 2001, this well was dry nearly year round with very little recovery during the winter-spring freshet period.

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[6] Hand dug wells originally dug and utilized starting in the late 1800s. A typical design was a 6' x 6' hole, hand dug down to approximately 25-60 feet below ground surface. Water was originally extracted using a rope, pulley and bucket but later as combustion and electric water pumps became available, they were used to provide water for irrigation and domestic purposes. The WWBWC field staff, through working with numerous well owners around the valley, that a majority of these wells have been either outright abandoned, re-drilled deeper using casing and/or back filled all due to them having gone partially or completely dry.

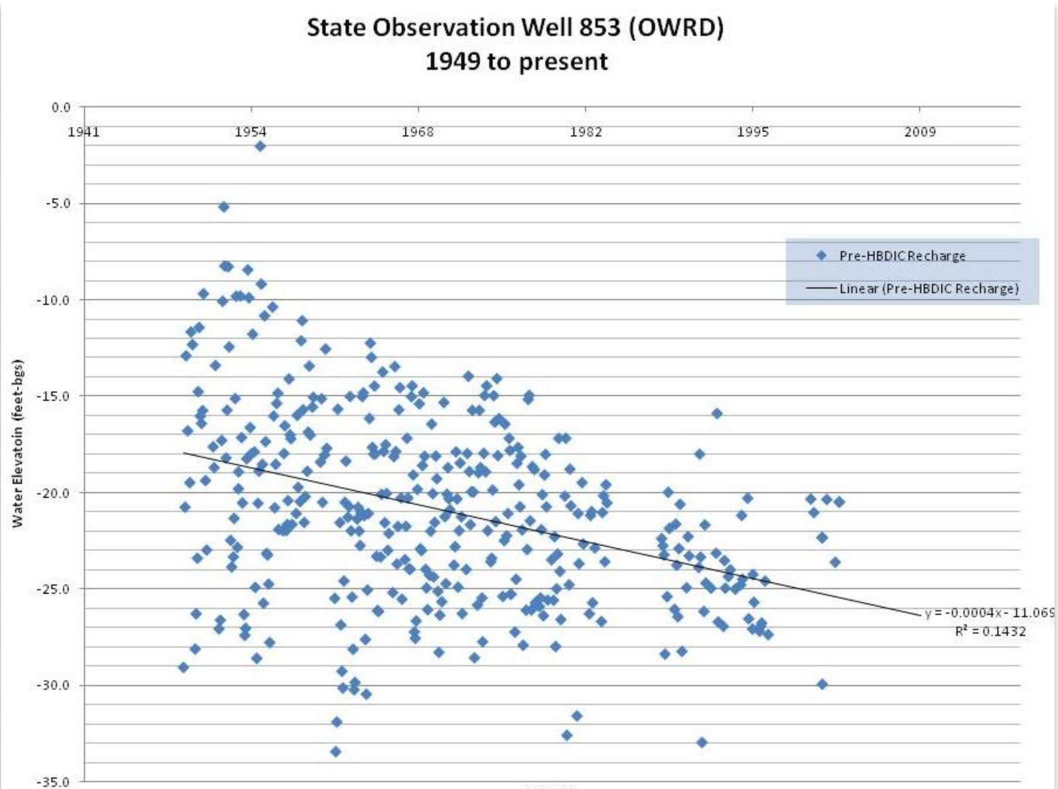

**Figure 9. Oregon State Observation Well (SOW 853 – WWBWC #GW-17) showing historic declines of shallow aquifer water table.**

Complementing the observation well data is the information provided by surface flow data collected at numerous springs across the Walla Walla River valley. Originally surveyed and measured by the USGS (Piper, 1933; Newcomb, 1965) these springs provide an excellent surficial indication of status of subsurface water supplies. In the early 1930s, Piper described these springs as a *"…integral part of the natural drainage system of the alluvial fan"* and likened them to *"the spillway of a reservoir, for they are supplied by overflow from the ground-water reservoir in the permeable alluvium… Consequently, the yield of the springs measures the decreased transmission capacity of the young alluvium."* (Piper, 1933)

He went on to note that well before his work in the 1930s, there were problem areas being identified with "*springs at the east end of the inner zone (Big Spring area) has decreased in the last 10-25 years.*[7]*"*, putting the start of the decline of the system somewhere around 1900. He also confronted the continuing debate that the springs were simply a product of up gradient water management practices such as flood irrigation by carefully noting: *"The regimen of the springs may well have been influenced in historic time by irrigation on the alluvial fans and flood plains but the springs were not created by that irrigation."* (Piper, 1933)

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[7] The Big springs may have gone done due to more water being diverted to the East and West Prongs of the Little Walla Walla River, since the mainstem or Tum-a-lum Branch was used mainly in the winter for a flood control channel.

Walla Walla valley spring systems generally occur in two areas, the Little Walla Walla River and the Mill Creek– Yellowhawk Creek systems. The focus of this report is on the area Piper termed the "inner zone" where more than 30 springs occur on a contour-arc across the Walla Walla River alluvial fan near Milton-Freewater, Oregon (**Figure** 10). The hydrogeology created by a combination of geologic events, alluvial sedimentology and variation in hydraulic conductivity play significant roles in determining where and why these springs emerge.

Many of these *inner zone* springs are still flowing today, although their output has decreased significantly over the years. Piper measured these springs during his work in 1932-1934 which was continued until the early 1950s by the state of Oregon. Newcomb (USGS, 1965) contrasted Piper's measurements to that of his own and concluded:

> *"Under the natural and irrigation recharging of the 1930's and 1940s about 50,000 acre-feet of water passed through the gravel unit and flowed from the outlets during the average water year. Water diverted by pumping from wells has modified this formerly normal discharge as have changes in the recharge resulting from irrigation and other water regulation practices."* (Newcomb, 1965)

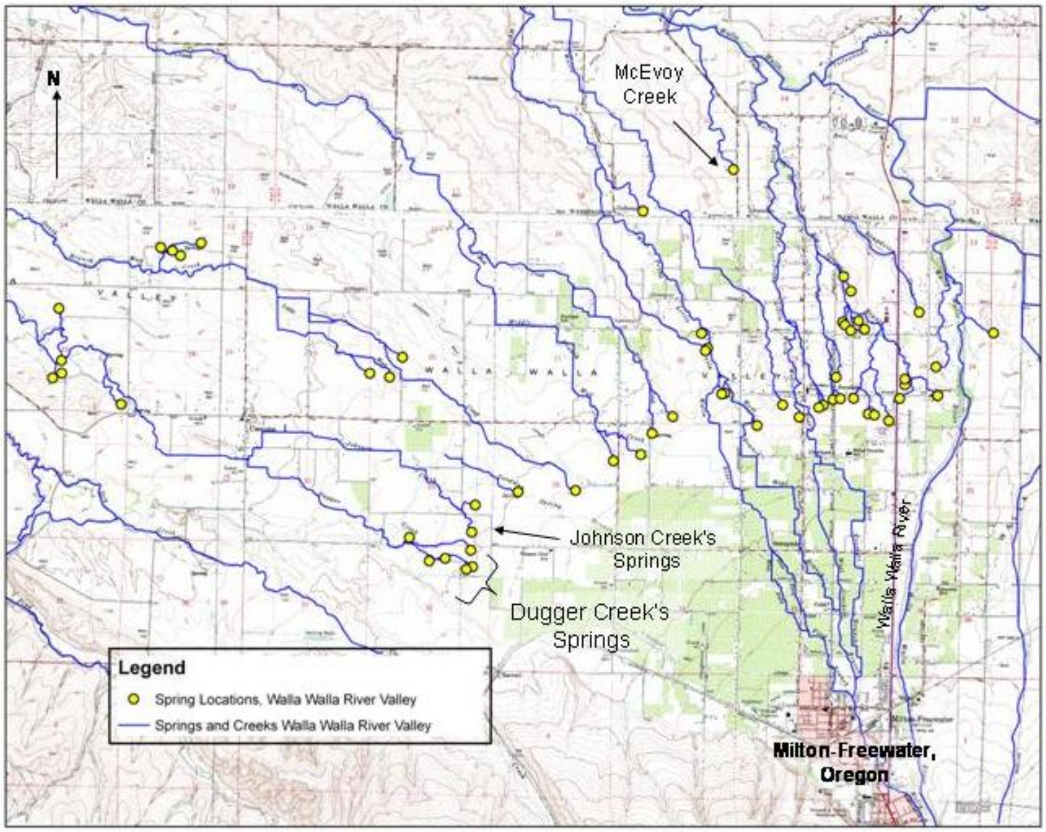

**Figure 10. Map of Walla Walla River system spring-creeks (Oregon only), showing the basic distribution of the inner zone.**

Starting in 2001, the WWBWC-Oregon State University Research team field surveyed these springs and set up flow monitoring stations at or as close as was feasible to where Piper had originally measured them. While the story tends to be the same across the inner zone spring system, the McEvoy Spring (just north of Washington/Oregon Stateline) is representative of their general degraded conditions. Measuring near the exact location measured in the 1930s, flows now represent a fraction of their historic averages (**Figure** 11). Also note the seasonal pattern of historical flows in McEvoy creek which are related to upgradient changes in irrigation water management and Little Walla Walla River flows.

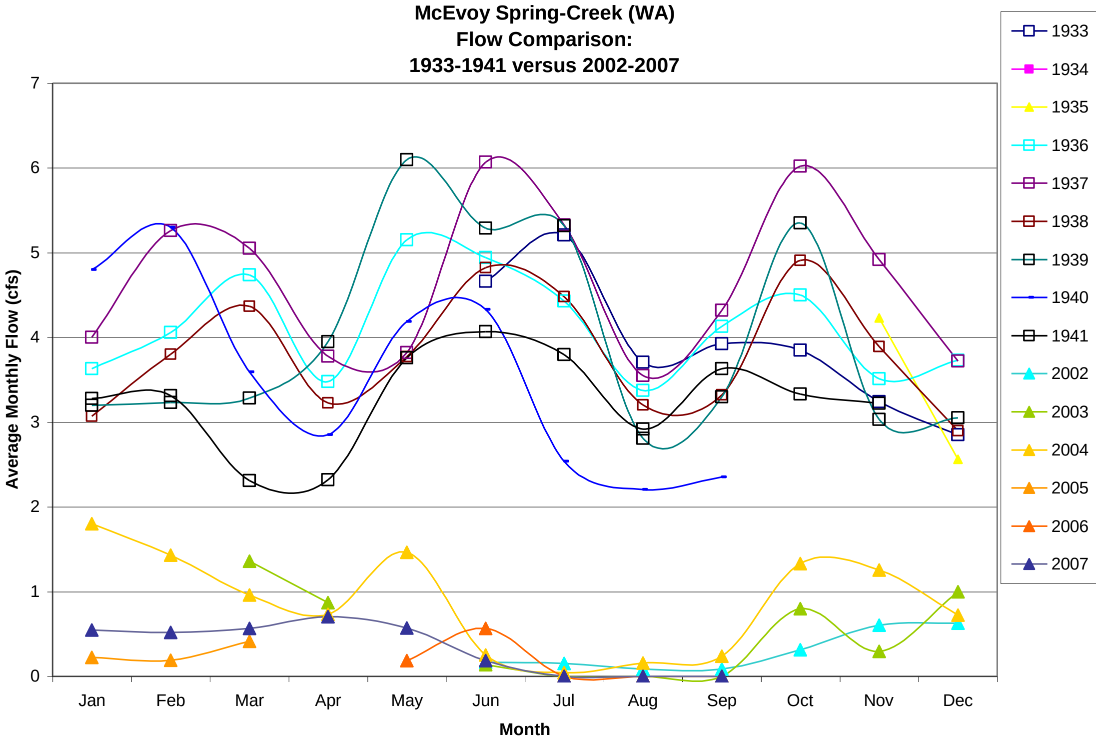

**Figure 11. Historic versus Current Flow monitoring on McEvoy Spring Branch, tributary to the Walla Walla River**

As of 2009, McEvoy Creek is often dry for a significant portion of the year. A local farmer and member of the Native Creek Society, Tom Page[8] was born, raised and still farms next to McEvoy Creek, and has publicly spoken many times about as his youth and being able to swim, fish for trout and irrigate out of the stream. Tom Page has worked to document the history of McEvoy Creek and many of the other valley spring-creeks providing some historical context to the loss of these natural resources.

*"The namesake of McEvoy Spring Branch was John McEvoy. John McEvoy was married to Flora McBean, the daughter of William McBean. William McBean settled in the Walla Walla Valley in the 1840's when he worked for the Hudson's Bay Company. He was the Clerk in Charge at Fort Walla Walla at the time of*

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[8] Tom Page is the co-founder of the Native Creek Society, has led a riparian and stream morphology restoration project and is operations lead for the McEvoy Spring Creek Aquifer Recharge Testing project.

> *the Whitman Massacre in 1847. When he retired from Company service in 1851 he filed for a Donation Land Claim (#39), one of a handful in the Walla Walla Valley. It is interesting to note where he staked the boundaries of his claim, a mile square and 640 acres. His reasoning must have been to encompass the most possible water resources within its boundary." (Page, 2007)*

Moving west on the contour-arc of the Walla Walla River springs and further from the major sources of recharged water; the flow volume situation gets significantly bleaker. Dugger Creek which is fed by springs that are the furthest west on the inner zone was measured in the early 1930s to be between 8-10 cfs through the summer season (USGS/OWRD data). The Dugger Creek drainage is now an area of high tension among water right holders due to what little irrigation season flows remain. Recently the WWBWC set up a gauge station directly at the site that Piper measured the 8-10 cfs, and in early July 2007 measured 2.1 cfs but by month's end the creek was completely dry.

Through the history of the Walla Walla basin there have been significant changes to the mechanisms that control both sides of this storage balance. Natural recharge has been altered in a number of ways, one of which is the historical manipulation of the streams and river's channel shapes and structures (**Figure** 12). Historically rivers were channelized for flood control structures, to increase agriculturally productive areas, and to allow for structures such as bridges and roads to be built. These actions while providing community benefits also resulted in rivers and streams that were shorter in length which in turn decreased the amount of resident-time that water was in the basin and available for recharge via channel bed infiltration. Additionally for decades the federal and states governments actively promoted the draining of wetland areas to increase agricultural production which also acted to reduce the recharge potential by decreasing the residence time water had in the basin.

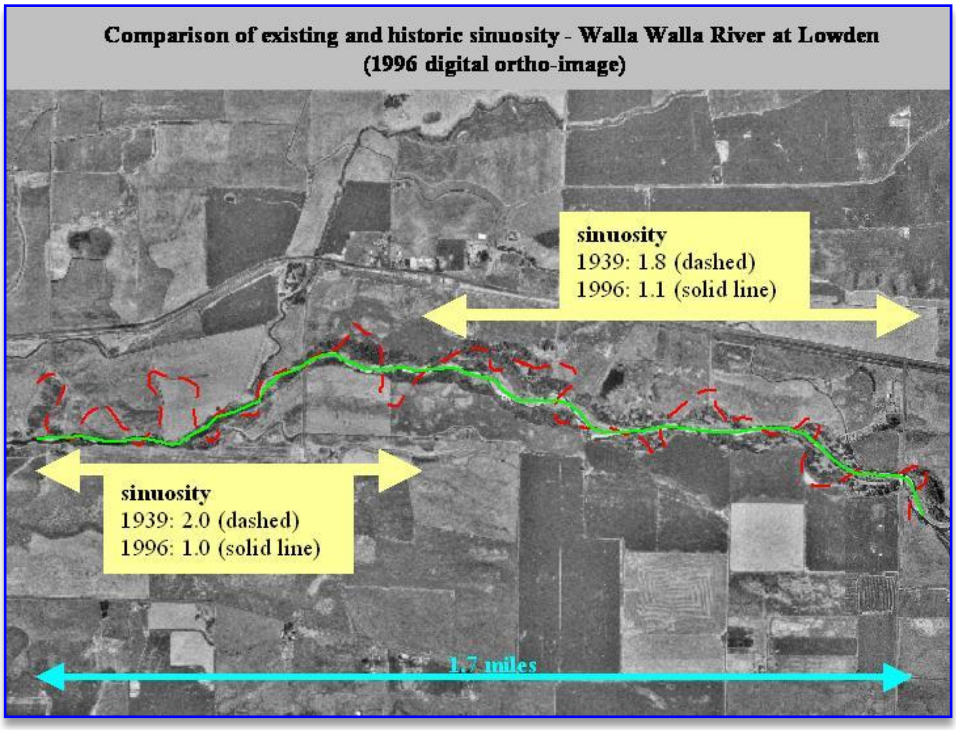
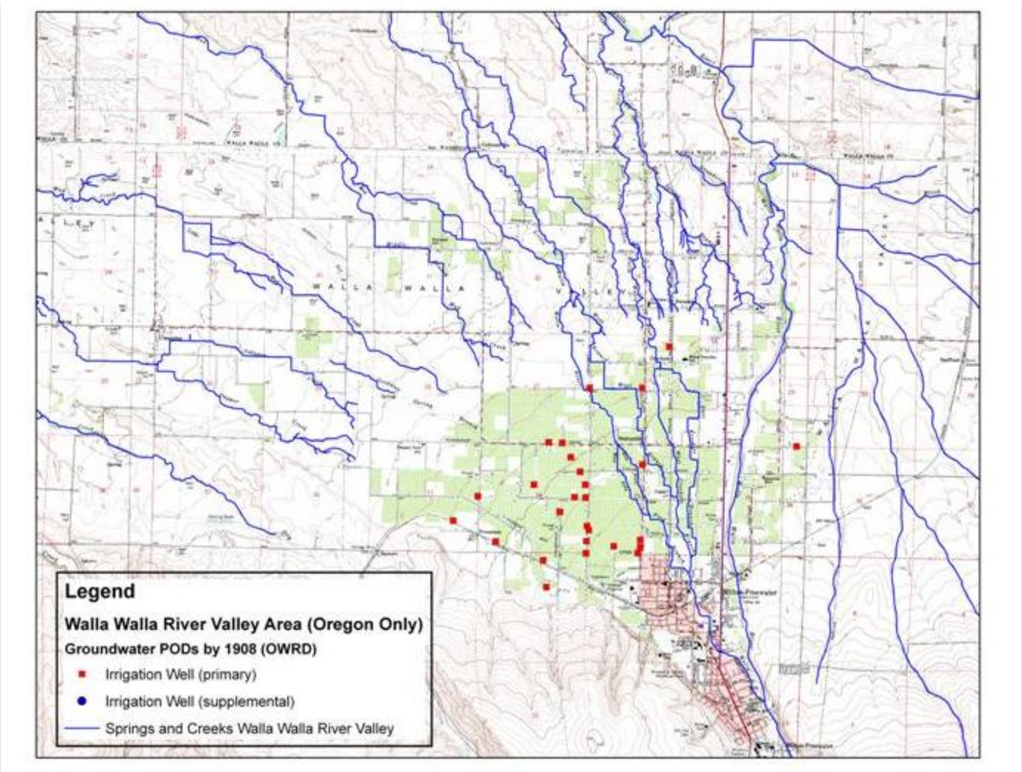


**Figure 12. Comparison of the Walla Walla River meanders from 1939 to 2006 (ODEQ, 2006)**

As irrigated agriculture became more prominent in the valley, the addition of lateral ditch systems and irrigation practices such as flood or rill irrigation acted to increase the recharge side of the balance. The USGS recently published a regionally relative report titled; *Estimates of ground-water recharge to the Yakima River Basin Aquifer System, Washington, for predevelopment and current land-use and land-cover conditions*.(USGS, 2006) In this report they quantified through modeling, the additional water contributed historically by irrigated agriculture to the groundwater storage balance. They estimated approximately a 38% (from 3.9 to 5.1 Million acre-feet) increase in recharged water entering the Yakima River aquifer from irrigation to that of pre-irrigation conditions. Therefore in the Walla Walla basin the expansion of irrigated agriculture has most likely added to the 'recharge' portion of the equation which has helped in part mediate for the dramatic increase in discharge or water use from the aquifer.

During the same period that irrigated agriculture was increasing the quantity of water being applied, the development of the aquifer's groundwater was taking place thus, increasing the discharge side of the storage balance ($\Delta \mathbf{S_G}$). Starting in the early 1900s, water wells were dug throughout the Walla Walla River valley for domestic, agricultural, municipal and industrial uses. Oregon Water Resource's Water Rights Information System (WRIS) database and Geological Information System (GIS) shows the numerous points of diversion (surface or groundwater) throughout the Oregon portion of the Walla Walla Basin, a significant majority of which are located in the Walla Walla River Valley.

Focusing specifically on Oregon's portion of the shallow aquifer, a WWBWC analysis of OWRD's WRIS GIS[9] database indicates that there are more than 650 permits[10] for irrigation wells with water rights totaling approximately 360 cfs, in the study area._Mapping this GIS information[11], **Figure** 13 (A, B, C, D) shows the historical progression of groundwater development in the Oregon portion of the shallow aquifer from 1908 to present. By 1908 primary irrigation wells were being permitted in the Walla Walla valley (**Figure** 13 A). About the time of the first hydrogeologic study of the basin (Piper, 1933), there was already a significant number of wells in the orchard area around Milton-Freewater (**Figure** 13B). When Newcomb was finishing his assessment, and Barker-McNish were starting their modeling project (USGS, 1976) permits for supplemental water rights, those used when the primary source (surface or groundwater) is no longer available due to lack of water, were becoming more prevalent for groundwater (**Figure** 13 C). And by December 31st, 2005, the permits for groundwater use had moved to all areas of the shallow aquifer system (**Figure** 13D).



**A. 1908**

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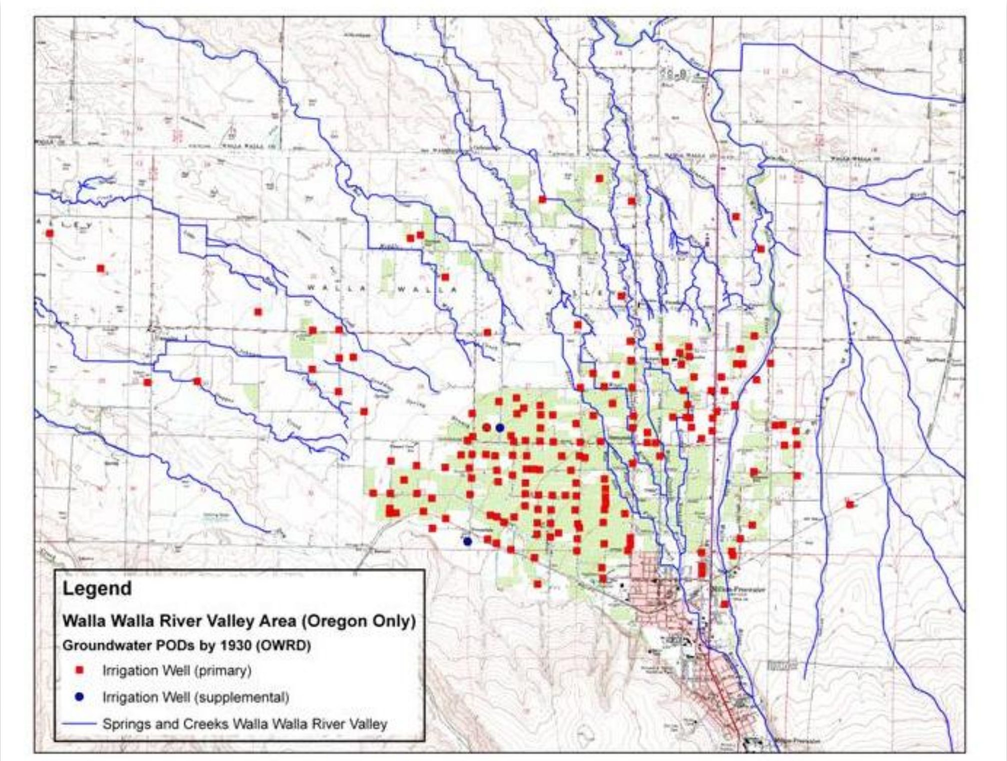
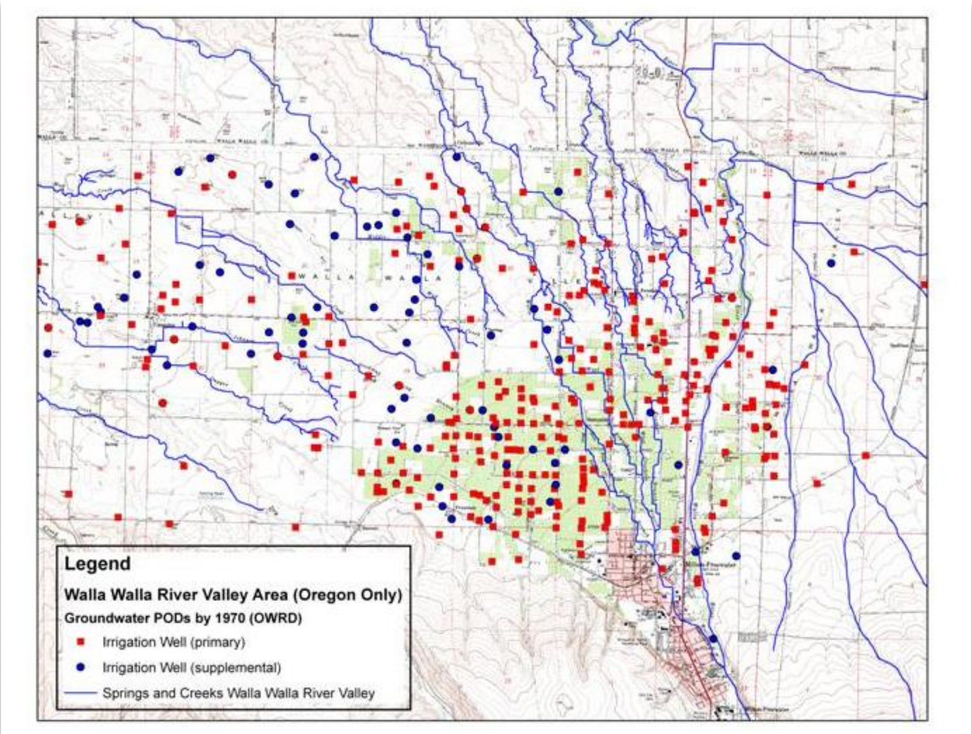
[9] http://www.wrd.state.or.us/OWRD/WR/wris.shtml

[10] Included in this data were wells cased into the confined, basalt aquifer system.

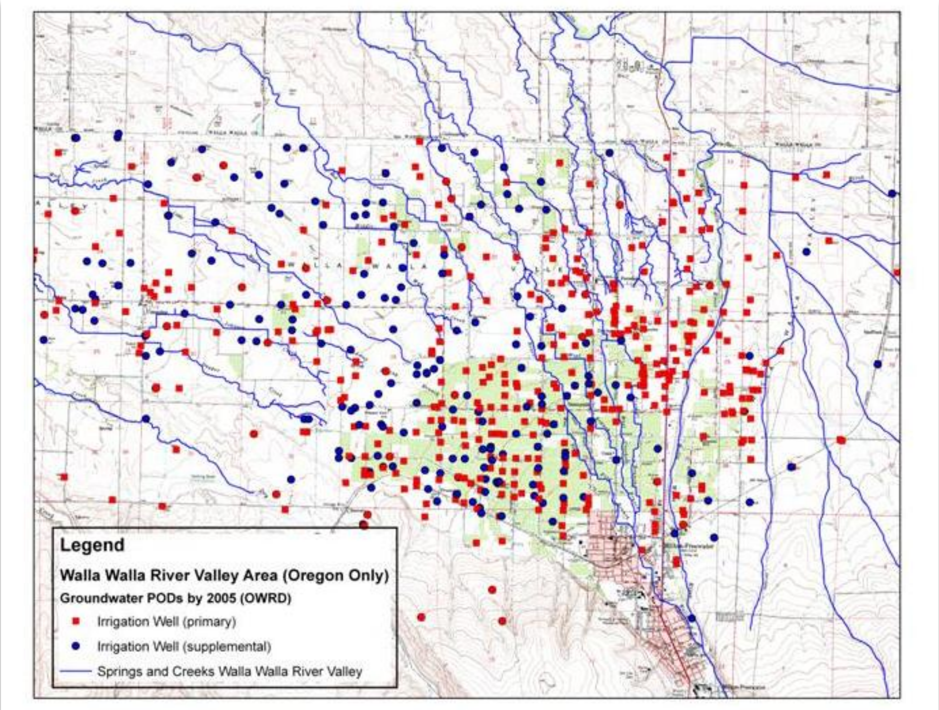
[11] Utilizing the GIS defined points of diversions and sorting them by priority date, a historical sequence of irrigation wells (water use codes IC, IS) was done by the WWBWC. Permits shown include those for wells drilled into the basalt, and do not include the exempt wells discussed by Wozniak.


Legend
Walla Walla River Valley Area (Oregon Only)
Groundwater PODs by 1930 (OWRD)
Irrigation Well (primary)
Irrigation Well (supplemental)
Springs and Creeks Walla Walla River Valley

B. 1930


Legend
Walla Walla River Valley Area (Oregon Only)
Groundwater PODs by 1970 (OWRD)
Irrigation Well (primary)
Irrigation Well (supplemental)
Springs and Creeks Walla Walla River Valley

C. 1970



**D. 2005**

**Figure 13. (A, B, C, and D) Historical Progression of Groundwater Development - Oregon: 1903-2005 (WRIS Data, 2006)**

Therefore the history of shallow aquifer development along with the surficial changes in water management has lead to dramatic changes to the shallow aquifer's water balance. The summation of these changes reflected in the historical groundwater levels and spring flows show a surface-groundwater system in decline.

## What is Managed Aquifer Recharge?

In the western United States, managed aquifer recharge or MAR has been used for decades as a tool to help resolve water management issues. Three of the most common applications of recharge are for subsurface water storage and retrieval, offsetting salt water intrusion issues in impaired coastal aquifers, and mitigating for groundwater pollution issues. The objective of MAR is to capture and store available water into underlying aquifers and in the case of aquifer storage and recovery (ASR) retrieve that water for use when surface water is scarce. Some of the most common methods used to 'artificially' recharge groundwater are things such as engineered spreading basins, direct well injection and the use of streams and irrigation ditches as surficial water infiltration systems.

Water managers in many parts of the world have proven it to be cost effective way to capture and store water for these and many other water management needs. Significantly lower costs, land availability, and surface associated environmental concerns have made it an attractive alternative to more conventional water management tools such as dammed surface reservoirs and desalination plants. In response to this growing demand the American Society of Civil Engineers has established a standardized set of guidelines for aquifer recharge for use as a water management tool in its publication titled *Standard Guidelines for Artificial Recharge of Groundwater* (ASCE, 2001). This publication gives a good general overview of the specific engineering, societal, and watershed planning issues associated with aquifer recharge and is an excellent place to start for those new to the field.

In the western United States two of the most prominent recharge projects occur in Orange County, California and in the Phoenix, Arizona metropolitan area. In southern California, Orange County Water District (OCWD) supplies water to millions of patrons via aquifer recharge and their renowned 'Groundwater Replenishment System[12] (**Figure** 14 and 15). In the technical circles of aquifer recharge, OWCD is often referred to as leaders in the application of aquifer recharge in the US, and many municipalities and other interested parties have toured and even trained with the OCWD staff to learn how they apply and maintain this tool for water management applications.

Their recharge program plays a large and critical role in supplying water on a year-to-year basis for their ever growing population:

> "*Groundwater reserves are maintained by a recharge system, which replaces water that is pumped from wells. OCWD's facilities have a recharge capacity of approximately 300,000 acre-feet per year. About two million people depend on this source for more than three-quarters of their water. Groundwater producers (city water departments and other local agencies) pump water from the groundwater basin and deliver it by pipeline to consumers.*[13] *(OWCD)*

While they have more than 9 separate recharge facilities, one of the largest are some former gravel pits that were converted into an aquifer recharge facility and "*currently recharge up to approximately 120 to 140 cubic feet per second (cfs) when full*."[14]

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[12] http://www.gwrsystem.com/about/background.html

[13] http://www.ocwd.com/_html/recharge.htm

[14] http://www.ocwd.com/_assets/_pdfs/_rfp/SantiagoCreekInitialStudy.pdf

**Figure 14. Anaheim Lake, one of OCWD's *recharge basins* (Courtesy of OCWD website)**

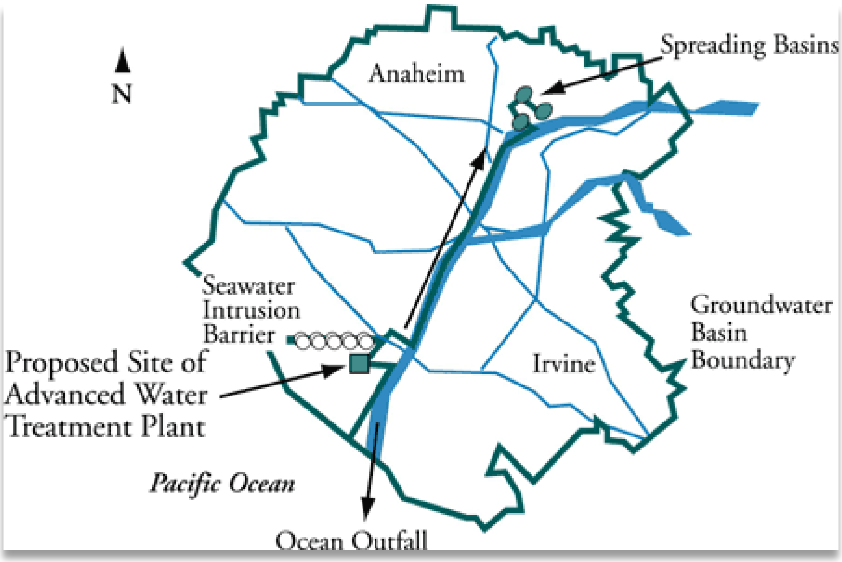

**Figure 15. Map of OCWD's "Groundwater Replenishment System" (Courtesy OWCD website)**

In the Phoenix Arizona metropolitan area aquifer recharge is also considered a critical component to its current and future water management planning needs. The Central Arizona Project or C.A.P.[15] project utilizes Arizona's allocation of Colorado River water (according to the multi-state, Colorado River Compact) to supply more than 1.5 million acre-feet annually to this region. Currently Arizona is not exercising its full allocation of Colorado River water rights. The unused portion which is in excess of 460,000 acre-feet annually is going to a multiple spreading basin aquifer recharge program, storing it for future use. The CAP program refers to aquifer recharge as playing:

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[15] http://www.cap-az.com/index.cfm

*"Recharge is a long-established and effective water management tool that allows renewable surface water supplies, such as Colorado River water, to be stored underground now for recovery later during periods of reduced water supply."*[16]

During August 2006, the WWBWC staff hydrologist participated in a tour of two CAP recharge projects just outside of Phoenix (**Figure** 16). A CAP hydrogeologist and project manager provided informative demonstration of projects whose geologic and hydrologic settings were similar to those experienced in the Walla Walla basin. This information has proven useful in the continued refinement of our local design efforts of this tool and application for our current water management issues.

**Figure 16. August, 2006, WWBWC staff toured the Aqua Fria Recharge Project outside Phoenix Arizona (Courtesy C.A.P. website)**

Locally MAR was first explored in the 1970s by the City of Walla Walla who began testing and implementing a direct injection Aquifer Storage and Recovery (ASR) program. This program stores water in the basalt aquifer during the high flow portions of the water year and then reclaims the water during the high demand summer season.

The list of national and international water programs that feature aquifer recharge as one of their management tools is extensive and too numerous to cover in this report. Setting up a system that complements and enhances the other water management strategies for the Walla Walla basin is merely a matter of designing and collaborating to find better ways to store water. With a better understanding of MAR application elsewhere, we can begin to discuss the water issues facing the basin and its intended application in solving those problems.

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[16] http://www.cap-az.com/static/index.cfm?contentID=81

## Managed Aquifer Recharge – Not a New Idea

From these early assessments documenting the decline of the aquifer and associated springs artificial aquifer recharge was considered early in the assessment process as it was recommended by the USGS in 1965. R.C. Newcomb's' report titled *Geology and Ground-Water Resources of the Walla Walla River Basin Washington-Oregon* (USGS, 1965) is considered to be one of the most comprehensive assessment of the Walla Walla basin's water resources. R.C. Newcomb, who was highly respected in his time, had worked extensively in the arid American west assessing the geology and hydrology of many hydrologic systems. He was an early proponent for using our understandings of subsurface geologic features to store and manage water resources. Before coming to the Walla Walla basin, he had worked elsewhere in the Columbia basin and published a series of studies, one of which was titled: *Storage of ground water behind subsurface dams in the Columbia River basalt, Washington, Oregon, and Idaho, by R.C. Newcomb* (USGS, 1961), demonstrating his innovative approach to finding cost effective ways of better managing water. For the Walla Walla basin he observed:

> *"Some initial tests at artificially recharging the gravel aquifers by placing excess surface water into gravel pits and onto unused gravelly fields have reportedly helped raise temporarily the water level in wells of their vicinities. A comprehensive plan for the systematic management of the old gravel as a water reservoir is an obvious need that will surely come about ultimately. Such a comprehensive plan and systematic management will need to include all phases of natural and artificial recharge in order to obtain maximum benefits from this important natural water-storage facility."(USGS, 1965)*

It was from Newcomb's early discussion of the potential of aquifer recharge that led the WWBWC and HBDIC to begin testing this tool. Additional interest was generated when further investigation revealed that there were other projects in the western United States (as discussed earlier) that had proven track records in recharge. Starting in 2003, a series of grants from the Oregon Watershed Enhancement Board (OWEB), the Walla Walla Watershed Alliance (WWWA) and in-kind contributions from the Hudson Bay District Improvement Company (HBDIC) allowed for the first successful limited testing license application, and subsequent installation and operation of the Hudson Bay Aquifer Recharge Project. The following sections will discuss the issues associated with aquifer recharge, the HBDIC project results to date, and aquifer recharge potential as a water management tool.

# PART II. THE HBDIC ALLUVIAL AQUIFER RECHARGE PROJECT

## Testing Managed Aquifer Recharge: HBDIC Site Operations and Monitoring (2004-9)

The Hudson Bay District Improvement Company (HBDIC) partnering with the Walla Walla Basin Watershed Council (WWBWC) sought and secured grant funding to test aquifer recharge starting in 2003. This project has been successfully operated for 6 recharge seasons and has been the main focus of the testing of MAR in the Walla Walla basin. This section reviews the results collected from the 2004-9 testing and helps provide the reader with a sense of how and what is monitored when testing MAR. There are two primary testing areas at the HBDIC Recharge Site; the spreading basins and the infiltration gallery testing areas. While the spreading basins have been operating since 2004, the infiltration galleries are relatively new being built during the 2008-9 recharge season.

To understand the application of aquifer recharge, hydrogeologic information about the aquifer-river system in the Walla Walla basin must be reviewed. For the purposes of simplification, this discussion focuses on the upper portion of the alluvial aquifer system, which is that portion of the alluvial system where groundwater is generally unconfined and hosted by gravelly strata. The basalt aquifer system will not be included in this discussion as its connection to surface water likely is minimal within the Walla Walla Basin (GSI, 2007). The deeper alluvial system also will not be discussed as it is at least semi-confined, hosted in and below extensive clayed strata, and probably has limited continuity to surface waters.

One of the first orders of business in defining the hydrogeology is to map the subsurface geologic features that influence the aquifer of interest. This subsurface mapping, sometimes referred to as hydrostratigraphic mapping, provides a three-dimensional, spatially-relevant description of the various layers (lenses, beds, formations) that comprise, or host, the aquifer system. Originally mapped by Newcomb in 1965, the alluvial aquifer system in the Walla Walla Basin generally is found within a mix of older river deposited (alluvial) clay, silt, sand, and gravel from the Blue Mountains, Missoula cataclysmic flood deposited silt and sand, and wind-blown loess.

The shallow or alluvial-aquifer system for our study area is present within a topographical depression, roughly triangular in shape bounded on the east by the Blue Mountains, the south and southwest by the Horse Heavens Hills, and the north and northwest by the Palouse slope. This alluvial aquifer system generally slopes from east to west, down the length of the Basin. The sloping aquifer receives most of its recharge from the Walla Walla River and Mill Creek drainages, although additional flow enters via the other smaller tributary drainages and through the subsurface. The water table gradient is generally east to west and its general movement is depicted in **Figure** 17. The basin has what we refer to as down gradient ‘pinch point’ through which surface water and groundwater eventually moves through. This point lies where the Walla Walla River crosses basalt outcrops at the base of Nine Mile Hill. The alluvial aquifer generally is considered to be *unconfined*, which means that it is open to receive water from the surface; and whose water table surface is free to fluctuate up and down, depending on the recharge/discharge rate. This condition is more prevalent in the upper portions of the valley and grows less so the further down gradient and west you move through the system due to increasing proportion of finer grained alluvium.

In 2007, utilizing funding from the Washington Department of Ecology and Oregon Watershed Enhancement Board, GSI Water Solutions Inc. completed a hydrostratigraphic mapping project of the Walla Walla River valley alluvial aquifer system (GSI, 2007). Five basic hydrostratigraphic units were defined and mapped in the alluvial aquifer system. All of these are sedimentary strata (e.g., clay, silt, sand, and gravel lithologies) overlying basalt bedrock, and sometimes referred to as the suprabasalt sediments. The five suprabasalt sediment units mapped for this project are the: (1) Quaternary fine unit, (2) Quaternary coarse unit, (3) Mio-Pliocene upper coarse unit, (4) Mio-Pliocene fine unit, and (5) Mio-Pliocene lower coarse unit. The terms Quaternary and Mio-Pliocene refer to geological time periods, Quaternary representing from 2 Million years ago till present, and the Mio-Pliocene referring to the late Pliocene through the Miocene periods (10.5 to 3.5 Million years ago). The younger Quaternary sedimentary units are on top of the older, Mio-Pliocene units (**Figure** 18 and 19).

An often used analogy for this alluvial aquifer system is to picture a large, multi-layered, silty, sandy, and gravel-to-cobble filled bath tub, with basalt bedrock acting as the walls and bottom of the tub. The structure contour map of the top of basalt clearly shows the shape of this basalt bath tub (**Figure** 20). This map also depicts the major folds and faults that influence the lateral continuity of the basalt bedrock and the overlying suprabasalt sediments. The degree of hydraulic continuity between the basalt (which hosts a variety of confined aquifers) and the suprabasalt (or alluvial) aquifer system is not well understood.

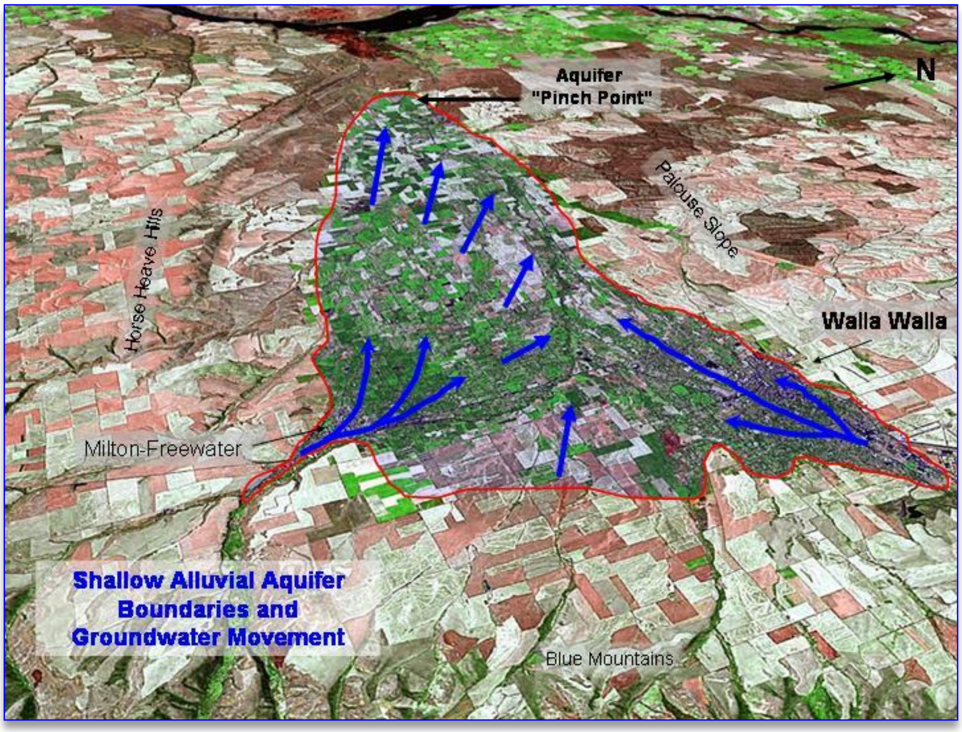


**Figure 17. Walla Walla River valley shallow aquifer system.**

Water is found in all of the sediment layers comprising the alluvial aquifer system, but it moves easiest through gravelly portions, which are most abundant near the surface. In addition to water moving through the gravel, water is also flowing in and out of it, moving between the gravel alluvial aquifer and water flowing over the surface in the form of rivers, streams and ditches. Because the system is pitched slightly toward the Columbia River, both the surface water and groundwater drain toward it. The thickest of the coarse alluvial hydrostratigraphic units is the Mio-Pliocene Upper Coarse Unit (**Figure** 19). These coarse strata form the primary unit in which alluvial groundwater is found in the Basin. For more information about the specific geologic information on the shallow aquifer please refer to Groundwater Solutions' report: *Geologic setting of the Miocene (?) to Recent Suprabasalt Sediments of the Walla Walla Basin, Southeastern Washington and Northeastern Oregon.* (GSI, 2007).

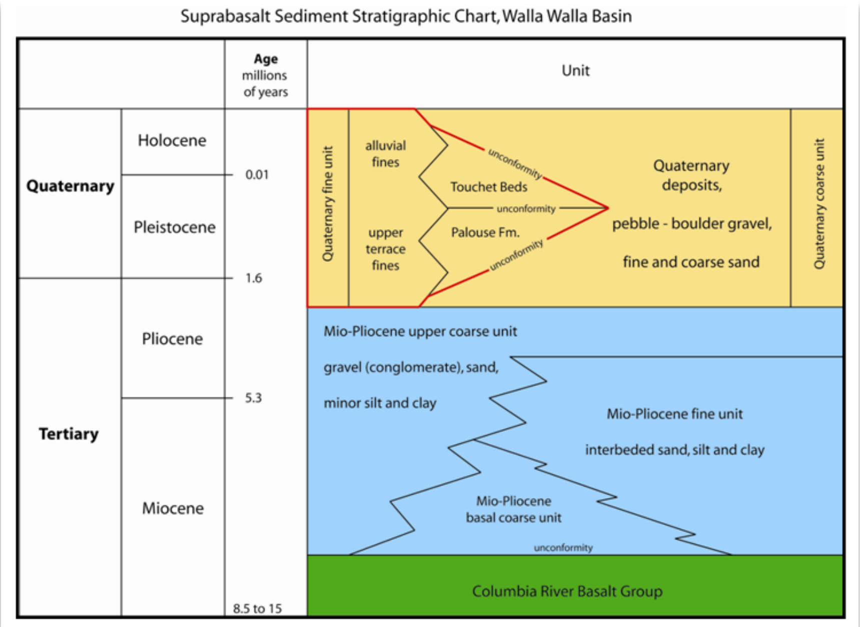


**Figure 18 Sediment Stratigraphic Chart of the Walla Walla shallow aquifer units (GSI INC et. al., 2007)**

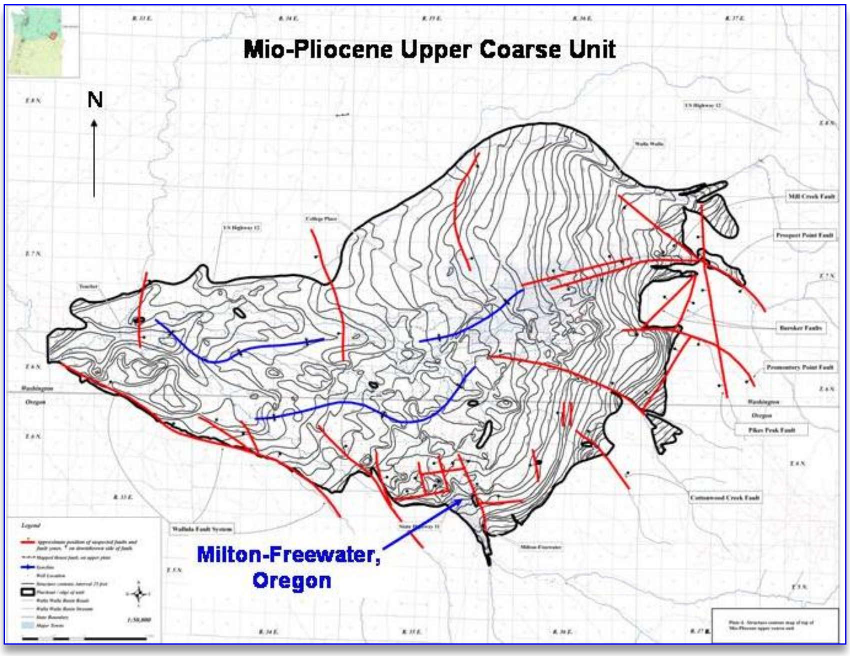


**Figure 19. Major sedimentary layer of the Walla Walla River Valley Shallow Aquifer. (GSI, 2007)**

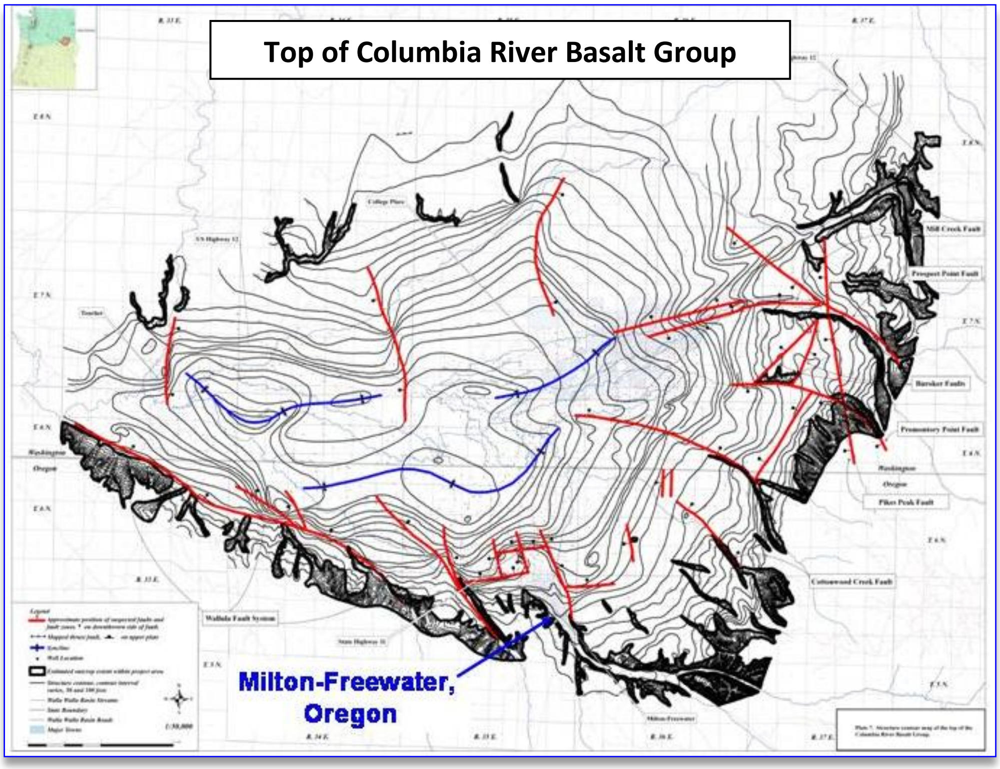


**Figure 20. Top of Columbia River basalt, or bedrock boundary for shallow aquifer (GSI, 2007)**

## Site Specific Hydrogeology and Geology

This section summarizes site specific geologic and hydrogeologic conditions, and is based on fieldwork at the Site and the basin wide hydrostratigraphic mapping presented in GSI (2007). The geologic cross-section in **Figure** 21 was derived from this hydrostratigraphic mapping effort.

The uppermost geologic unit in the Test Site area is a sequence of interstratified silt and sand (Touchet Beds) comprising the Quaternary fine unit. However, at the site itself, these strata are absent and the uppermost unit is the coarse Quaternary unit. The coarse Quaternary unit at the Site consists of basaltic, sandy to clayey, uncemented gravel. Beneath the Test Site, geologic logging during site specific monitoring well drilling showed that these uncemented strata are approximately 20 feet-thick. The basin-wide mapping effort suggests these strata thicken to the west of the site.

Uncemented strata of the coarse Quaternary unit are underlain by the variably indurated (uncemented to cemented) Mio-Pliocene upper coarse unit. Site specific monitoring wells drilled for the project do not fully penetrate this unit. However, basin-wide hydrostratigraphic mapping (GSI, 2007) suggests this unit is approximately 150 to 160 feet thick in the immediate vicinity of the Site. Based on regional trends, interpretations of driller's logs, and our geologic logging of drill cuttings samples collected from recently drilled wells in the general area, the Mio-Pliocene upper coarse unit consists of variably indurated, weakly to moderately cemented, silty to sandy, indurated gravel (conglomerate). This unit is the primary host unit for the alluvial aquifer system in the general vicinity of the Site. The coarse Quaternary unit – Mio-Pliocene upper coarse unit contact was identified using the following combination of criteria:

- A notable change in cuttings color from gray dominated hues to brown and yellow-brown hues
- Presence of cemented sand clasts and sand cemented to pebble and cobble clasts in the cuttings samples
- Increased mud content in the fine fraction of the cuttings
- Generally better air circulation reported by the driller

The functional base of the upper portion of the alluvial aquifer system in the area of the Site is essentially the top of the Mio-Pliocene fine unit. The contact between this unit and the overlying Mio-Pliocene upper coarse unit is predicted to lie approximately 200 feet below ground surface at the Site. Although there will be a degree of hydraulic continuity between these two units, the prevalence of laterally extensive clay and silt lithologies in the fine unit limits this.

The deepest part of the alluvial aquifer system in the Site area is hosted within a locally occurring coarse interval referred to as the Mio-Pliocene basalt coarse unit. This unit differs from the upper coarse unit. It is generally felsic, displaying thin (<10 feet thick) quartz sand layers. It also is saturated and may indeed make a locally productive water-bearing interval. However, the thickness and wide lateral extent of the overlying fine unit is inferred to greatly limit the hydraulic connection of this unit to the upper coarse unit and surface waters.

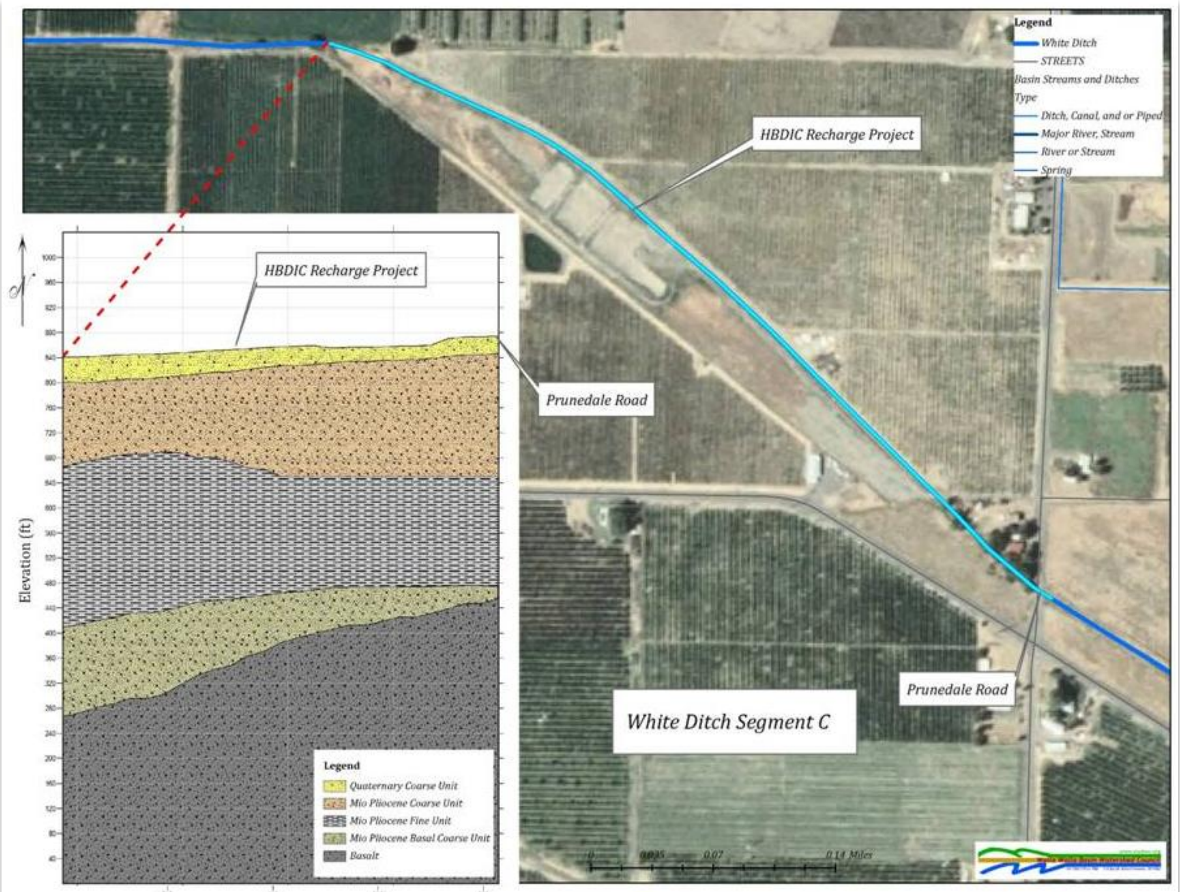


**Figure 21. Geologic Transect of White Ditch at HBDIC Recharge Site (Baker T. , 2010)**

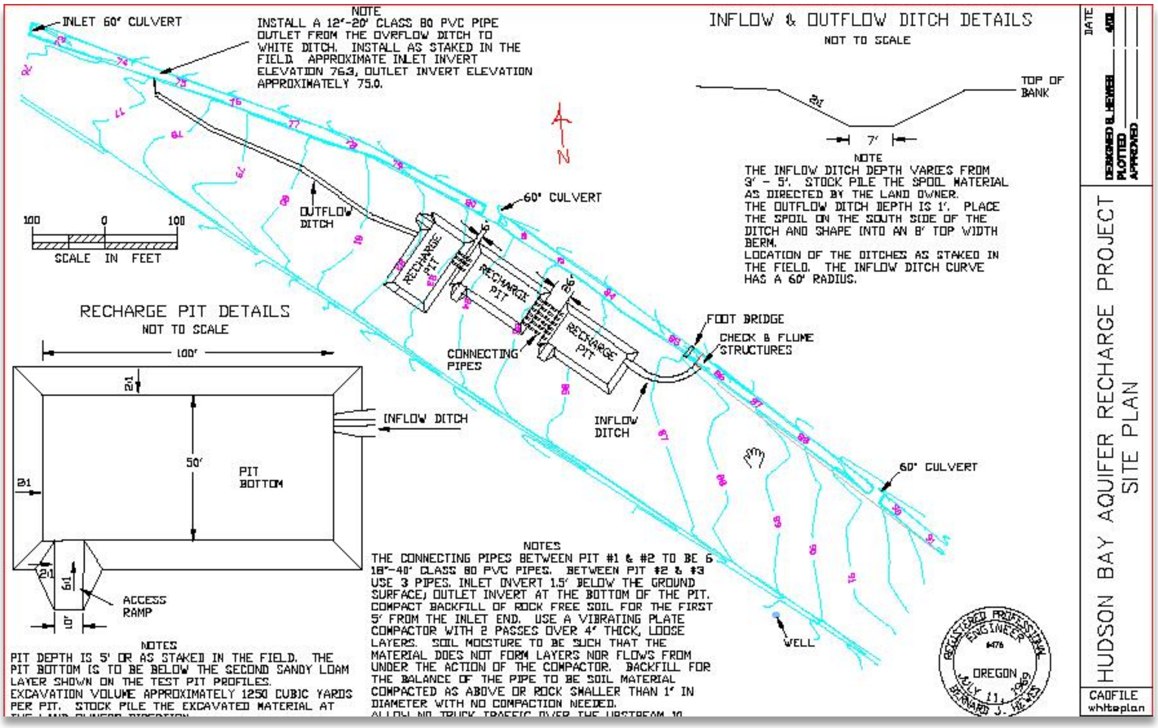
A number of studies and reports have looked at the hydrologic conditions of the various geologic stratigraphy mentioned above. The most recent work was done by the WWBWC-OSU team as portion of the Integrated Surface Water-Groundwater Flow Model (IWFM) project in 2006-8 (Petrides, 2008). A series of aquifer tests were performed at various times of the year including a 72-hour constant-rate pumping test and a step-drawdown pumping test at observation well #1 (GW-46) on the HBDIC Recharge site. The hydraulic conductivity value from that testing of the upper two layers of the aquifer ranged from 22 – 34 meters/day with a groundwater velocity at approximately 1 meter day. Other estimates of hydraulic conductivity are based on modeling and literature reviews. The USGS estimated values from their modeling exercise (MacNish, 1976) gave ranges (depending on geologic unit) from 4 - 65.84 meters/day. The literature (Bear, 1972) provides values for unconsolidated sand and gravel in $10^1$ meters/day with the EPA (EPA, 1986) estimating 27 - 30 meters/day (Petrides, 2008).

## The HBDIC Alluvial Aquifer Recharge Site

### Overview

Starting in 2004, the HBDIC Recharge site was operated over 6 consecutive seasons. The site began operations in March of 2004 after receiving the OWRD limited testing license (OWRD #LL-758) in

February 2004 and construction being completed as the project was first turned on in March 2004. This first season was unlike the subsequent seasons because the site was being operated even before it was completed. This was mainly due to the HBDIC-WWBWC team wanting to get some aquifer recharge testing completed before the shut off date of May 15th, 2004. From 2005-2009 site construction was done during the winter shutdown period (February 1st onward) or done parallel to the site being operated. The site was expanded twice during this period. The first (2004-5 season) from 0.34 acres to 1.1 acres when the three original 50' x 100' spreading basins (**Figure** 22) were expanded, with spreading basin #1 being more than tripled in size. During the 2005-6 seasons, a fourth basin was added bringing the total basin area to 1.4 acres with an average depth between 5'- 7'.



NOTE
INSTALL A 12"-20' CLASS 80 PVC PIPE OUTLET FROM THE OVRFLOW DITCH TO WHITE DITCH. INSTALL AS STAKED IN THE FIELD. APPROXIMATE INLET INVERT ELEVATION 76.3, OUTLET INVERT ELEVATION APPROXIMATELY 75.0.

NOTE
THE INFLOW DITCH DEPTH VARIES FROM 3' - 5'. STOCK PILE THE SPOIL MATERIAL AS DIRECTED BY THE LAND OWNER.
THE OUTFLOW DITCH DEPTH IS 1'. PLACE THE SPOIL ON THE SOUTH SIDE OF THE DITCH AND SHAPE INTO AN 8' TOP WIDTH BERM.
LOCATION OF THE DITCHES AS STAKED IN THE FIELD. THE INFLOW DITCH CURVE HAS A 60' RADIUS.

NOTES
PIT DEPTH IS 5' OR AS STAKED IN THE FIELD. THE PIT BOTTOM IS TO BE BELOW THE SECOND SANDY LOAM LAYER SHOWN ON THE TEST PIT PROFILES.
EXCAVATION VOLUME APPROXIMATELY 1250 CUBIC YARDS PER PIT. STOCK PILE THE EXCAVATED MATERIAL AT

NOTES
THE CONNECTING PIPES BETWEEN PIT #1 & #2 TO BE 6 18"-40' CLASS 80 PVC PIPES. BETWEEN PIT #2 & #3 USE 3 PIPES. INLET INVERT 1.5' BELOW THE GROUND SURFACE; OUTLET INVERT AT THE BOTTOM OF THE PIT. COMPACT BACKFILL OF ROCK FREE SOIL FOR THE FIRST 5' FROM THE INLET END. USE A VIBRATING PLATE COMPACTOR WITH 2 PASSES OVER 4" THICK, LOOSE LAYERS. SOIL MOISTURE TO BE SUCH THAT THE MATERIAL DOES NOT FORM LAYERS NOR FLOWS FROM UNDER THE ACTION OF THE COMPACTOR. BACKFILL FOR THE BALANCE OF THE PIPE TO BE SOIL MATERIAL COMPACTED AS ABOVE OR ROCK SMALLER THAN 1" IN DIAMETER WITH NO COMPACTION NEEDED.

**Figure 22. Original HBDIC Site Designs 2003 – Engineering by Bernie Hewes, PE Oregon**

The spreading basins were operated successfully for 5 recharge seasons until the summer of 2008 just before the original OWRD limited testing license expired (February 2009). The HBDIC-WWBWC team informed OWRD resources that it intended to submit for a water right for the site through their department, the logical progression after successful limited license testing. Due to limitations in the OWRD Umatilla Basin Rules for the Walla Walla basin restricting aquifer recharge in this portion of the watershed, OWRD put together a Rules Advisory Committee (RAC) during the summer 2008. The Confederated Tribes of the Umatilla Indian reservation voiced concerns over aquifer recharge competing for non-irrigation season flows with a reservoir feasibility study they have been working on with the United States Army Corps of Engineers-Walla Walla (USACE). After several RAC meetings, it was decided that the HBDIC-WWBWC team would request another OWRD Limited testing License whilst awaiting the

CTUIR-USACE team to further work out their feasibility study details. This was applied for during the winter 2009 and received in time to operate the remaining of the 2008-9 recharge season. Since that decision, the CTUIR-USACE are advocating the Columbia River Pumping exchange project instead of the Pine Creek Reservoir, thus removing the potential for a water availability conflict between the two programs. Negotiations between the OWRD, HBDIC-WWBWC and CTUIR-USACE teams will now need to commence during this current limited license in order to allow the HBDIC project to apply for and receive a successful water right. Additionally through the collaboration of the groups mentioned above, aquifer recharge is now included in the CTUIR-USACE feasibility study to help protect and enhance Walla Walla River flows for salmon recovery. Currently no RAC meetings are scheduled but will need to be conducted before summer 2013 in order for the HBDIC site to receive a water right.

Starting in the fall of 2008, a portion of the HBDIC recharge site has been used as a test location for examining and comparing the performance of four different types of shallow aquifer recharge infiltration galleries. This test area is shown in **Figure** 23 below. Many of the local irrigators would like to implement shallow aquifer recharge on their farms, but do not have the space for spreading basins. Subsurface Infiltration galleries are being tested on the HBDIC site as a potential solution. A diagram in Appendix III shows the layout of the four galleries, water turnout, the location of meters, and piezometers to track groundwater responses.

### Spreading Basins Operations

The HBDIC site consists of two operating areas, the first being the spreading basins the main focus of this document, with the second area designated for infiltration gallery testing, which will be covered in more detail in a later section. To conduct the recharge testing, the HBDIC project can divert a total of up to 50 cfs (OWRD LL#1059) from the Walla Walla River at the Little Walla Walla Diversion (OWRD # 14012100) during the November 1st through May 15th recharge period. OWRD, in the limited license, established minimum instream flows for the Walla Walla River that must be met at the Nursery Bridge (M-4) gauge (**Figure** 23) downstream of the HBDIC diversion. These minimum instream flows were determined through the OWRD limited testing license process in 2004 in consultation with Oregon Water Resources Department (OWRD), Oregon Department of Fish and Wildlife (ODFW), Oregon Department of Environmental Protection (ODEQ) and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). Minimum instream flows are only applicable to this project and any other OWRD water right currently diverting water from the Walla Walla River.

Other instream flow agreements such as the one completed under Civil Penalty agreement between the US Fish and Wildlife Service (USFWS) and the three main irrigation districts on the river do not apply to the HBDIC Recharge site Limited License requirements. The minimum instream flows and their applicable diversion periods for the HBDIC recharge site are listed in Table 1.

| HBDIC Recharge Site Legal Diversion Periods | Minimum Walla Walla River Flow (cfs) |
|---|---|
| November 1st through November 30th | 65 cfs |
| December 1st through January 31st | 95 cfs |
| **February 1st through May 15th** | **150 cfs** |

**Table 1. HBDIC Minimum Instream Flow Requirements**

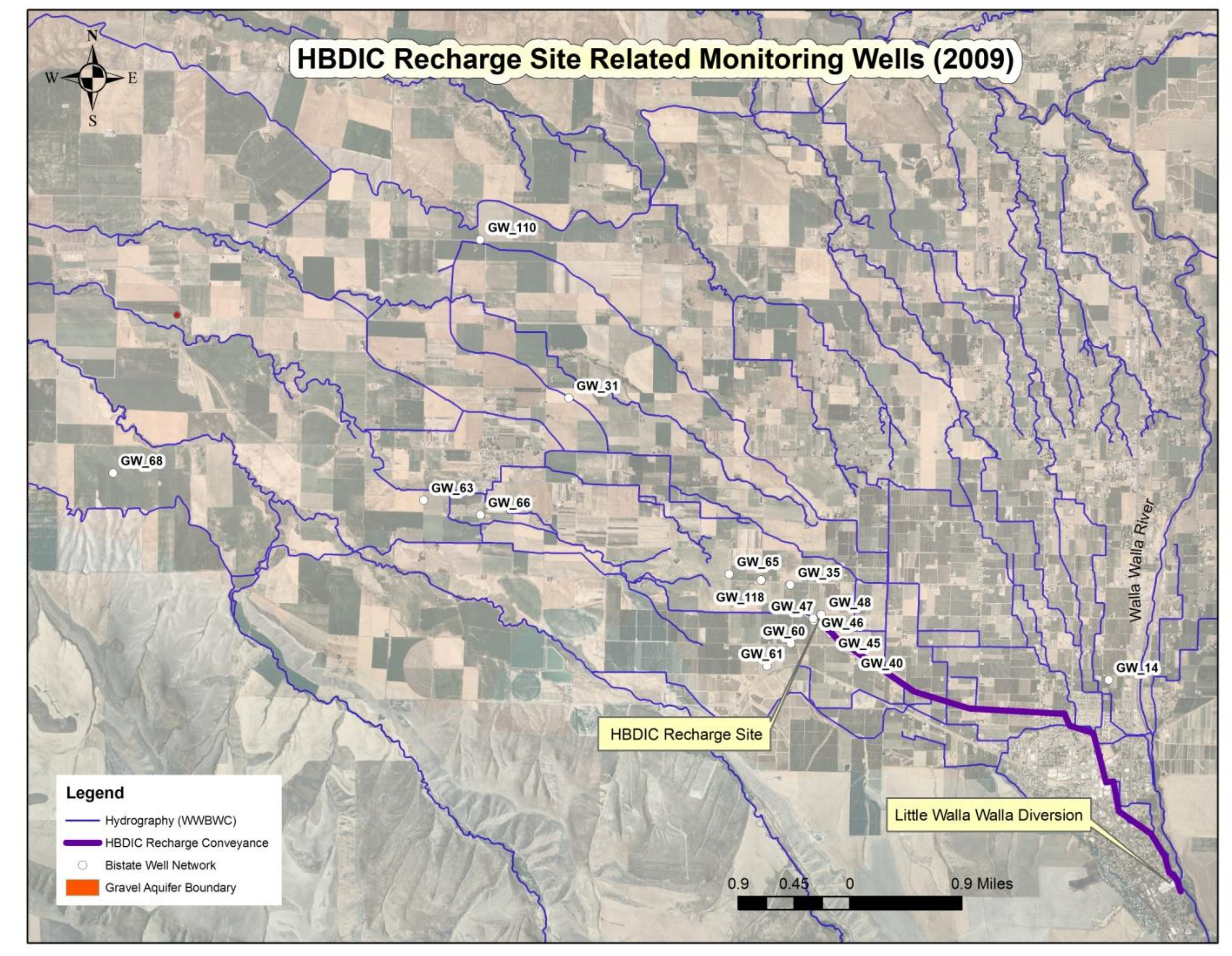


**Figure 23. Map of HBDIC Recharge site and Source Water Delivery System**

**Figure** 24 shows the average daily flow volumes for the Walla Walla River compared to those of the Little Walla Walla Diversion and the HBDIC recharge site flows for 2009 water year. Walla Walla

River Irrigation District and Hudson Bay District Improvement Company both divert a majority of their water rights at the Little Walla Walla River site at Cemetery Bridge (OWRD Gauge # 14012100). HBDIC White Ditch diverts water from the Little Walla Walla system at the OWRD HBDIC Gauge (OWRD Gauge # 14012300). The HBDIC recharge project diverts water from the White Ditch based on the instream flow values and other water user's priority as described earlier. HBDIC recharge flows represent only a small fraction of the total flow in the Walla Walla River during the November through May 15th operating period (**Figure** 24).

From the Little Walla Walla diversion, HBDIC recharge water flows to a split in the Little Walla Walla River system called the frog. At the frog HBDIC has an OWRD operated gauge station (OWRD # 14012300) to help monitor and manage their water use off the Little Walla Walla River system. The recharge water then flows into the White Ditch, HBDIC's main canal which flows for about 2.5 miles to the site's intake (**Figure** 25). The water then flows through the project filling the basins SP-1, SP-1B SP-2, SP-3, SP-4 with excessive water tailing back into the White Ditch. The intake and flow between each of the basins is maintained by HBDIC field staff and is controlled using a series of weir boards to control rates of flow in and through the project.

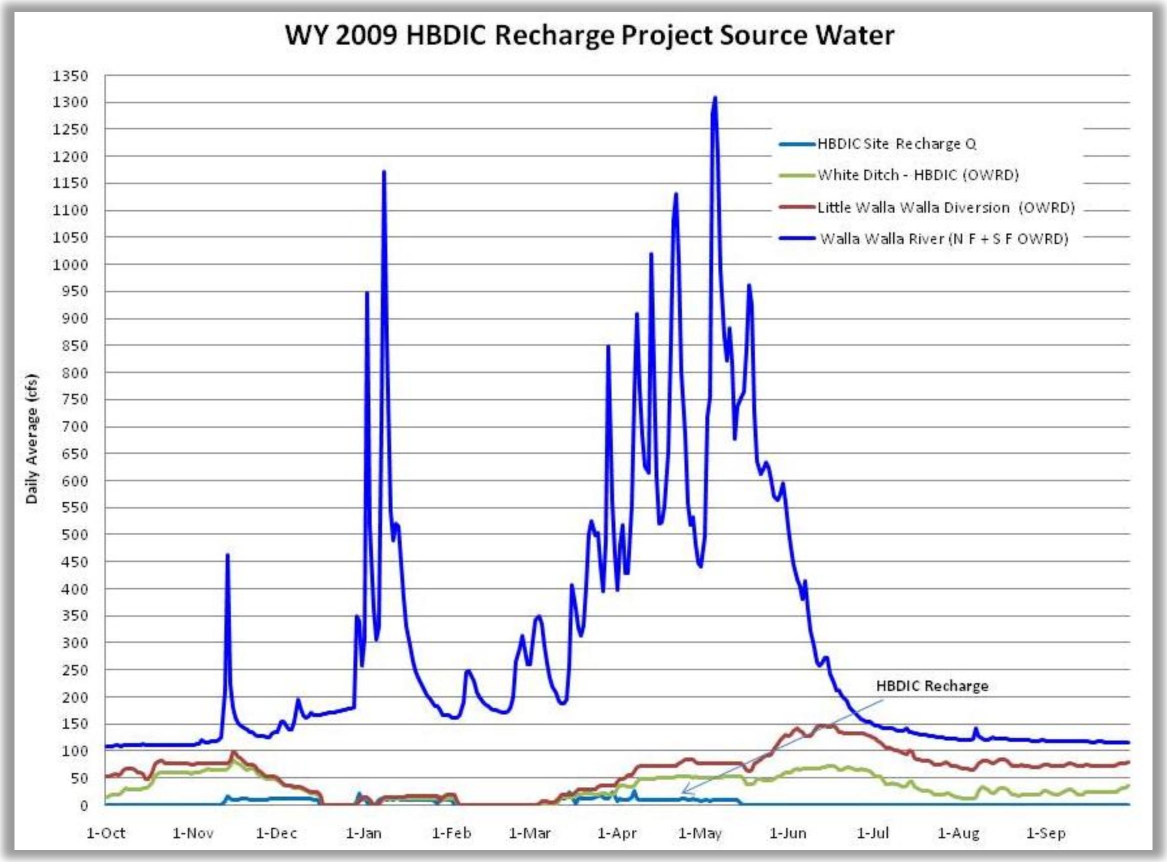


**Figure 24. Comparison Walla Walla River source water to Diversions and Use (WY 2009).**

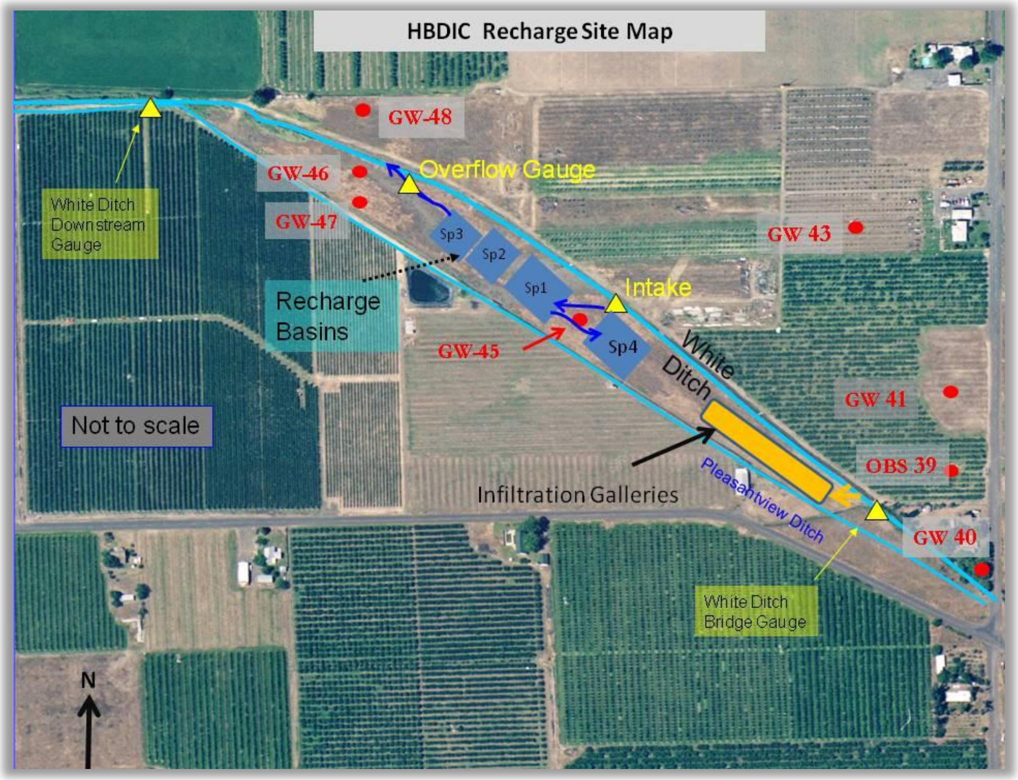


**Figure 25. Aerial Map of HBDIC Recharge Site with Monitoring**

Flow is measured into the project in the intake weir structure where an unvented *In-situ LT-100* level logger records water level in PSI. Atmospheric PSI data is also collected on site and at the WWBWC office to help correct for water levels in the weir. Using the engineered weir rating table, water level data is converted into 15-minute flow data and is compiled annually... Tail water leaving the site is measured in a portable ramp flume using the same equipment described above. Both the intake and overflow sites have physical staff gauges with which to check the electronic logger measurements against actual physical water levels. This provides calibration information for the logger data and ensures correction against drift and other recorder abnormalities. Data is plotted for a visual check by WWBWC hydrology staff and then used to calculate recharge rates and water usage at the site for testing and reporting purposes.

### Spreading Basins Recharge Results

To calculate the total recharge volume and average recharge rate at the HBDIC site, instantaneous overflow data (cfs) is subtracted from the instantaneous intake data (cfs). The amount of water delivered to the Site in each season of operations has varied from a low of 409 acre-feet in 2004 to a high of 3234 acre-feet in 2006-2007 (Table 2). These amounts were calculated using stage data measured in the flume that delivers water into the Site. The stage data was measured using a digital data logger and pressure transducer programmed to measure depth of water through the flume hourly. Table 2 presents our calculated daily average recharge rate (in cfs) and total volume delivered (in acre-feet) for the site each recharge season, or portion of a recharge season. Table 2 also lists total infiltration basin area which has changed over time as the site has been periodically expanded. Comparing the area of the basins to the volume delivered shows us that recharge efficiency at the Site has varied over time.

The delivery of water to the site is influenced by a number of factors that are independent of site operation. Inflow to the site is susceptible to water elevation conditions in the White Ditch where upstream users can turn off, suddenly increasing the amount of water entering the project, making the overflow channel a necessity and the inflow data vary greatly. Alternatively, up gradient water users diverting water can cause the project to run below it optimal recharge potential. During the winter operational months, periods of low water temperatures can influence the rate at which water can infiltrate; decreasing water temperature equates to increasing water viscosity. All of these physical issues influence effective recharge rates, which are manifest in the variability in average daily Q seen in **Figure** 26.

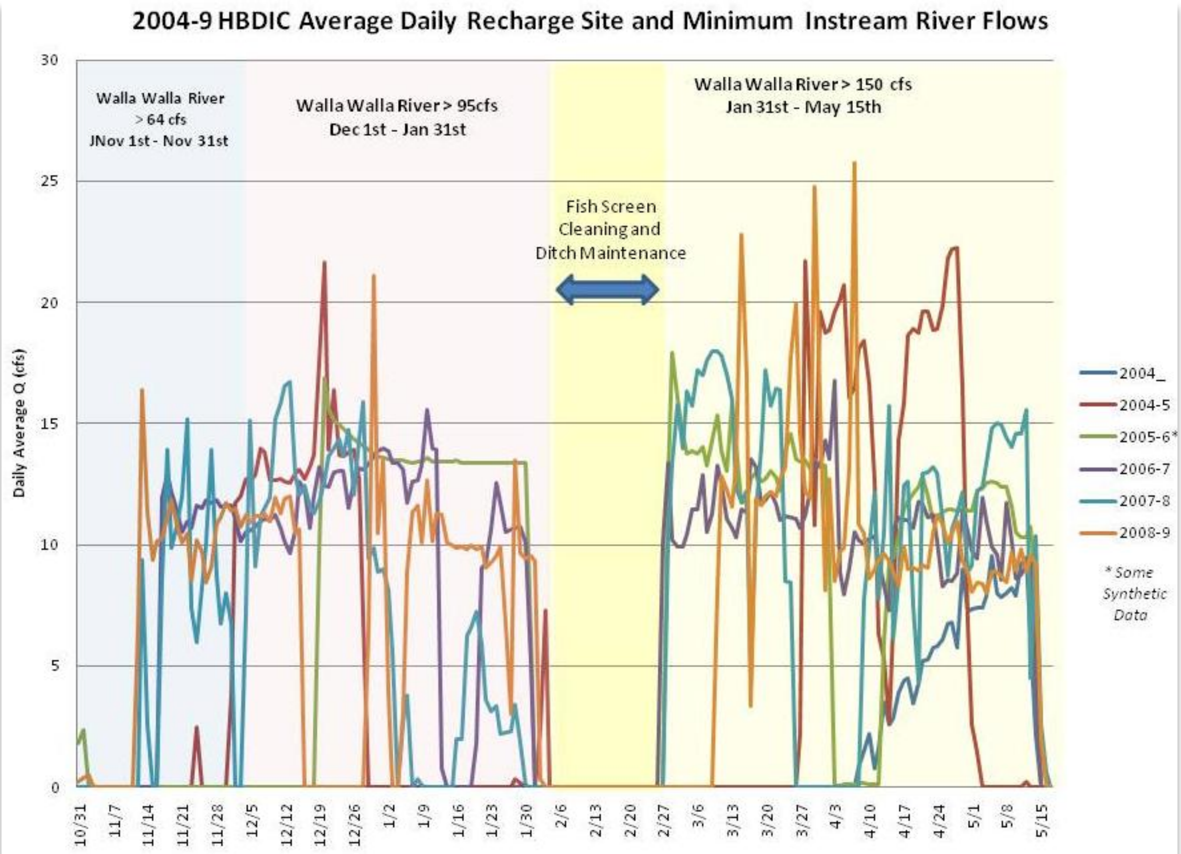
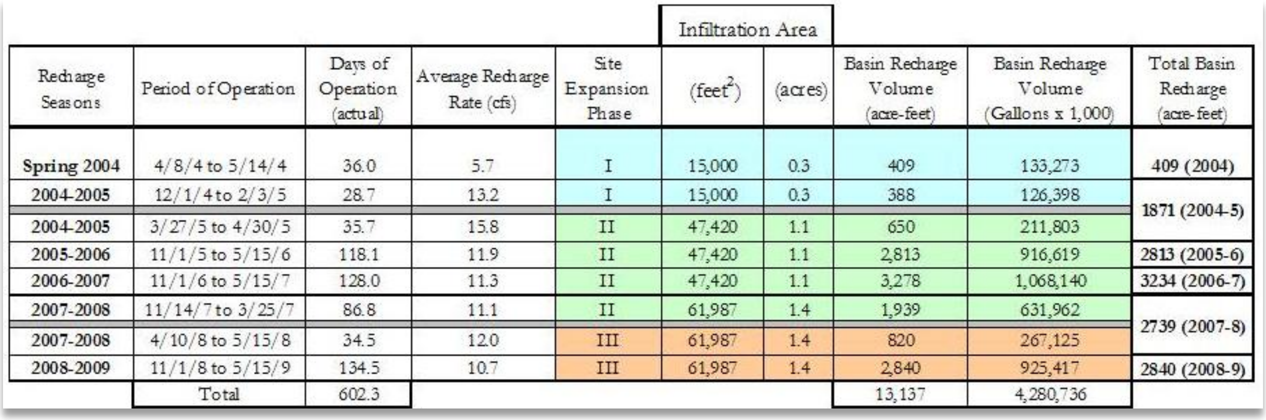


**Figure 26. 2004-9 HBDIC Recharge Flows (daily average – cfs)**

Reviewing the average daily flows, it generally appears that the period between November 1st through February 1st has a decreased recharge rate overall but is also less sporadic in the flow peaks than the February 21st through May 15th period. As shown above, the period starting on February 1st is the period for HBDIC and Little Walla Walla River system shutdown. This shutdown is due to two factors: 1) The fish screen structure located at the Little Walla Walla diversion needs to be cleaned every year in order to be effective and 2) the instream flow requirement for the HBDIC project goes from 95 cfs to 150 cfs on February 1st. This, coupled with the generally low flow seen in the river at this time due to cold temperature and headwaters snow packs, makes it a good time to service the fish ladders and turn off the system. Consequently both the WWRID and HBDIC irrigation districts now perform some of their ditch maintenance to correspond to this off period.

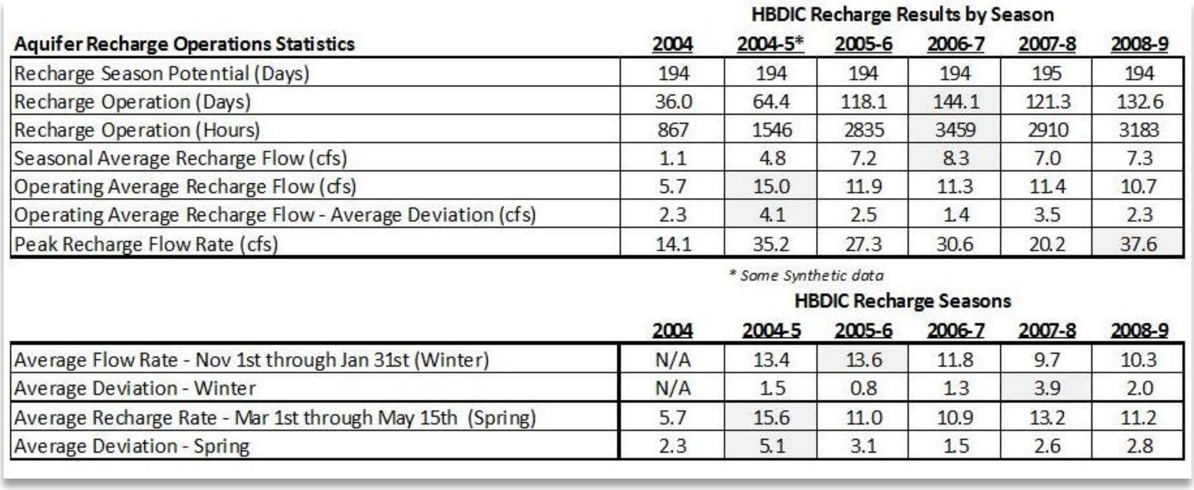


| Recharge Seasons | Period of Operation | Days of Operation (actual) | Average Recharge Rate (cfs) | Site Expansion Phase | Infiltration Area (feet$^2$) | Infiltration Area (acres) | Basin Recharge Volume (acre-feet) | Basin Recharge Volume (Gallons x 1,000) | Total Basin Recharge (acre-feet) |
|---|---|---|---|---|---|---|---|---|---|
| **Spring 2004** | 4/8/4 to 5/14/4 | 36.0 | 5.7 | I | 15,000 | 0.3 | 409 | 133,273 | **409 (2004)** |
| **2004-2005** | 12/1/4 to 2/3/5 | 28.7 | 13.2 | I | 15,000 | 0.3 | 388 | 126,398 | **1871 (2004-5)** |
| **2004-2005** | 3/27/5 to 4/30/5 | 35.7 | 15.8 | II | 47,420 | 1.1 | 650 | 211,803 | |
| **2005-2006** | 11/1/5 to 5/15/6 | 118.1 | 11.9 | II | 47,420 | 1.1 | 2,813 | 916,619 | **2813 (2005-6)** |
| **2006-2007** | 11/1/6 to 5/15/7 | 128.0 | 11.3 | II | 47,420 | 1.1 | 3,278 | 1,068,140 | **3234 (2006-7)** |
| **2007-2008** | 11/14/7 to 3/25/7 | 86.8 | 11.1 | II | 61,987 | 1.4 | 1,939 | 631,962 | **2739 (2007-8)** |
| **2007-2008** | 4/10/8 to 5/15/8 | 34.5 | 12.0 | III | 61,987 | 1.4 | 820 | 267,125 | |
| **2008-2009** | 11/1/8 to 5/15/9 | 134.5 | 10.7 | III | 61,987 | 1.4 | 2,840 | 925,417 | **2840 (2008-9)** |
| | Total | 602.3 | | | | | 13,137 | 4,280,736 | |

**Table 2. 2004-9 HBDIC Spreading Basins Operations for Surface Flows**

Clearly, actual water usage for the HBDIC site has been influenced by changes in foot-print and size. These included the "construct-as-you-run operations "of the spring 2004 season, to the HBDIC site upgrades during mid-recharge season (2004-5 and 2007-8). The periods and days of operations also varied depending on Walla Walla River flow conditions, water temperatures, and at times due to water users needs in the system. The site expansions were numbered I, II and III with the infiltration areas increasing from 0.3 acres (15,000 ft$^2$) to 1.4 acres (61,987 feet$^2$). The season for the highest total recharge rate was the second half of the 2004-5 season (15.8) cfs while the most effective year for total volume recharged was the 2006-7 season (3234 acre-feet). Over the six year period the site was operated for a total of 602 days for a total of 13,137 acre feet or over 4 billion gallons of water.

To better understand variations in recharge rates, volumes relative to changes in operation days and infiltration area were further calculated from the HBDIC site operations statistics (Table 3). With 194 potential operational days in a recharge season (as defined by the limited license) the 2006-7 year showed the highest number of operating days (144.1) and hours (3459). This was also the year having the highest *seasonal* average recharge rate (8.3 cfs) where average recharge is divided by the total number of potential recharge days. The 2004-5 recharge season showed the highest *operating* recharge rate (15 cfs) as well as the highest average deviation. The high average deviation suggests a higher variability in the recharge rate. For the purposes of clarity, the term *effective average recharge rate* used throughout the rest of this document refers to the highest *operating recharge rate.*



HBDIC Recharge Results by Season

| Aquifer Recharge Operations Statistics | 2004 | 2004-5* | 2005-6 | 2006-7 | 2007-8 | 2008-9 |
|---|---|---|---|---|---|---|
| Recharge Season Potential (Days) | 194 | 194 | 194 | 194 | 195 | 194 |
| Recharge Operation (Days) | 36.0 | 64.4 | 118.1 | 144.1 | 121.3 | 132.6 |
| Recharge Operation (Hours) | 867 | 1546 | 2835 | 3459 | 2910 | 3183 |
| Seasonal Average Recharge Flow (cfs) | 1.1 | 4.8 | 7.2 | 8.3 | 7.0 | 7.3 |
| Operating Average Recharge Flow (cfs) | 5.7 | 15.0 | 11.9 | 11.3 | 11.4 | 10.7 |
| Operating Average Recharge Flow - Average Deviation (cfs) | 2.3 | 4.1 | 2.5 | 1.4 | 3.5 | 2.3 |
| Peak Recharge Flow Rate (cfs) | 14.1 | 35.2 | 27.3 | 30.6 | 20.2 | 37.6 |

* *Some Synthetic data*

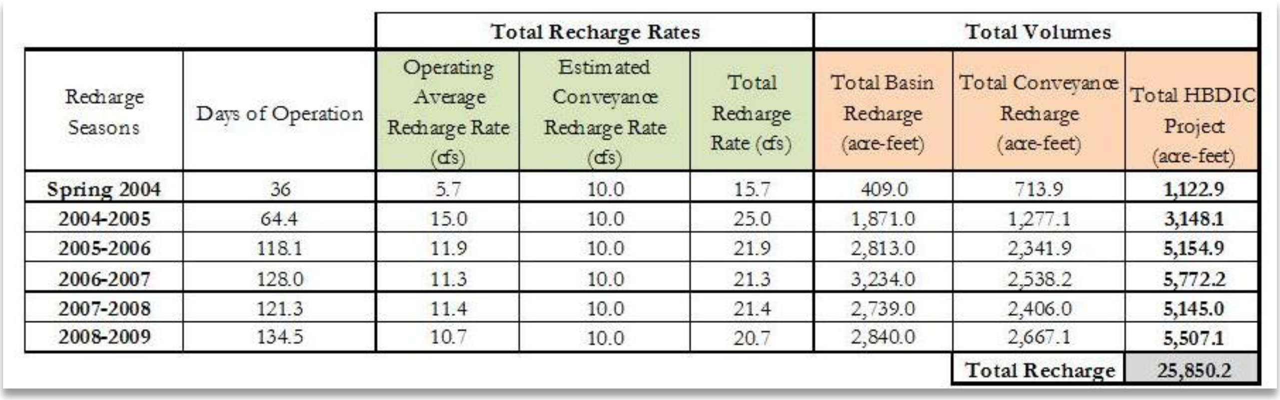
HBDIC Recharge Seasons

| | 2004 | 2004-5 | 2005-6 | 2006-7 | 2007-8 | 2008-9 |
|---|---|---|---|---|---|---|
| Average Flow Rate - Nov 1st through Jan 31st (Winter) | N/A | 13.4 | 13.6 | 11.8 | 9.7 | 10.3 |
| Average Deviation - Winter | N/A | 1.5 | 0.8 | 1.3 | 3.9 | 2.0 |
| Average Recharge Rate - Mar 1st through May 15th (Spring) | 5.7 | 15.6 | 11.0 | 10.9 | 13.2 | 11.2 |
| Average Deviation - Spring | 2.3 | 5.1 | 3.1 | 1.5 | 2.6 | 2.8 |

**Table 3. HBDIC Recharge Site Operational Statistics**

Calculating the total *effective* recharge rate as well as the total recharge volumes for the HBDIC project also requires estimating the amount of water lost in conveyance in the White Ditch from Little Walla Walla Diversion to the site. This is required by the limited license. Various ditch loss studies have been conducted by the WWBWC, OSU and others with varied results and confidence levels. For the purposes of this report an estimated conveyance loss of 10 cfs was used to calculate the total values for the project. This value is based on the HBDIC manager's operational knowledge of this system (e.g. constantly supplying known volumes of water to his patrons) and is supported by reviewing the OWRD Gauge and HBDIC intake data during periods when only the HBDIC site is in operations. Like the spreading basins on site, this 10 cfs value likely varies with temperature, flow volumes and other factors.

To conclude, Table 4 shows that the total *effective* recharge rate for the site and ditch appears to average around 22 cfs with an average total volume of around 5,000 acre-feet (excluding the spring 2004 season). To provide perspective, 5,000 acre-feet is the equivalent of 7.8 miles$^2$ a foot-deep in water. The ~ 22 cfs *effective* recharge rate means that the spreading basins portion of the HBDIC site and the ditch supplying water to the site is currently utilizing 44% of its total allowed recharge rate from the Walla Walla River.



| | | Total Recharge Rates | | | Total Volumes | | |
|---|---|---|---|---|---|---|---|
| Recharge Seasons | Days of Operation | Operating Average Recharge Rate (cfs) | Estimated Conveyance Recharge Rate (cfs) | Total Recharge Rate (cfs) | Total Basin Recharge (acre-feet) | Total Conveyance Recharge (acre-feet) | Total HBDIC Project (acre-feet) |
| **Spring 2004** | 36 | 5.7 | 10.0 | 15.7 | 409.0 | 713.9 | **1,122.9** |
| **2004-2005** | 64.4 | 15.0 | 10.0 | 25.0 | 1,871.0 | 1,277.1 | **3,148.1** |
| **2005-2006** | 118.1 | 11.9 | 10.0 | 21.9 | 2,813.0 | 2,341.9 | **5,154.9** |
| **2006-2007** | 128.0 | 11.3 | 10.0 | 21.3 | 3,234.0 | 2,538.2 | **5,772.2** |
| **2007-2008** | 121.3 | 11.4 | 10.0 | 21.4 | 2,739.0 | 2,406.0 | **5,145.0** |
| **2008-2009** | 134.5 | 10.7 | 10.0 | 20.7 | 2,840.0 | 2,667.1 | **5,507.1** |
| | | | | | | **Total Recharge** | **25,850.2** |

**Table 4. Total Water Usage Values for the HBDIC Recharge Site (2004-9)**

## Deciphering the Variations in Recharge Volumes and Rates

As we review the water usage data provided in Tables 2 through 4 it becomes apparent that rates and volumes of recharge for the HBDIC site do not seem dependent solely on infiltration area or intake management. As discussed earlier there are many operational and physical factors that likely influence the effectiveness of the project to help replenish the shallow aquifer system. However there are other factors not mentioned in the previous section that also can influence the effectiveness of the spreading basins to replenish the shallow aquifer. For the purpose of this report we will review data relative to the following potential influences:

1. Seasonal Temperature Fluctuations
2. Seasonal and Long-term Infiltration Basin Clogging
3. Water Table Mounding

## Seasonal Temperature Fluctuations

While the HBDIC-WWBWC team did not conduct an in-depth research project coupling the *effective* rates of recharge with the water and air temperatures at the site, it is a well established fact that water becomes more viscous with decreasing temperatures. This physical factor would have the effect of making it more difficult to recharge at maximum *effective* rates during the cooler portions of the recharge season typically from November 1st through February 28th. **Figure** 27 shows a basic comparison of average recharge rates for the first and second halves of each recharge season. While there does appear to be some variability in rates, it is not clear that temperature (e.g. first half (blue) dramatically influences the *overall effective* rate of recharge. A more in-depth site study where continuous water temperatures are measured against recharge rates would help to better define this potential operational consideration for the HBDIC site.

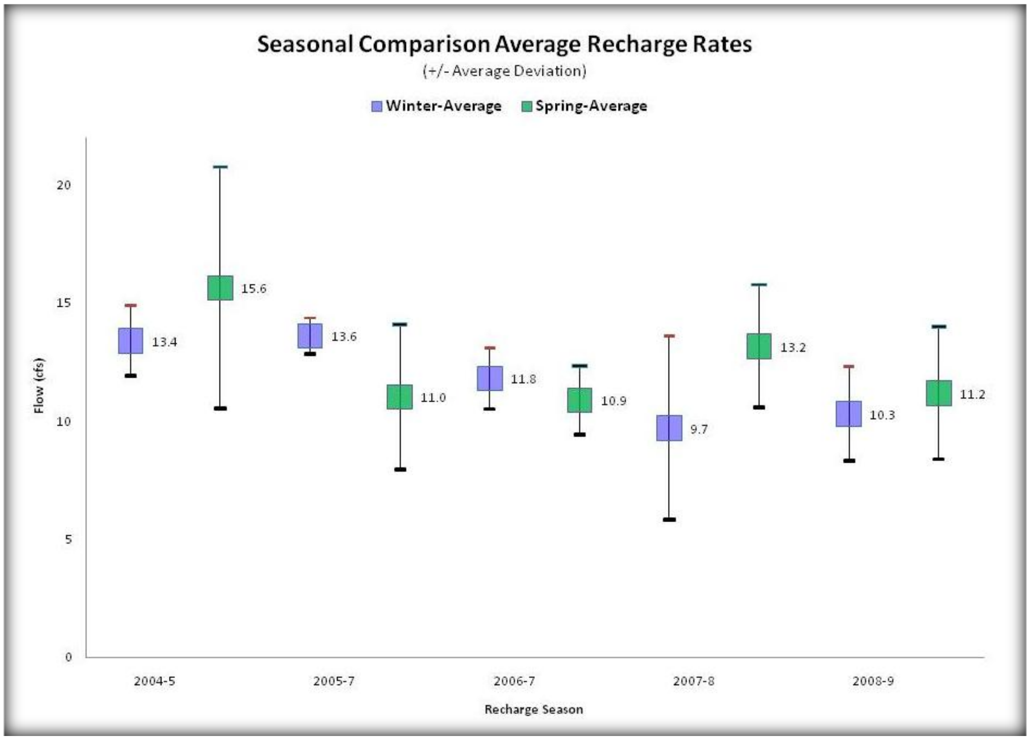


**Figure 27. Comparison of fall vs. Winter *Effective Recharge Rates for Temperature***

## Water Table Mounding and/or Basin Clogging

When we reviewed the overall rate information provided in Table 4 it became necessary to further partition the recharge rates and volumes based on infiltration areas. Therefore recharge rates were first grouped and graphed by infiltration areas (**Figure** 28). By doing this we could clearly see trends in the data. For the spring 2004 season and the first half of the 2004-5 seasons, rates varied a great deal. Some of this could likely be explained by the site construction operation limitations during the spring, but considering that the 13.4 cfs value in a 0.34 acre surface area is very high relative to the other seasons there may be other factors at work. Because this was the first portion of a season where all three original basins were operated it could be tied to the site being unclogged and ready for maximum infiltration. It should be noted that when engineering the design for the first 3' x 50' x 100' foot ponds, a small-pit slug test was performed. That test showed an infiltration rate in this much smaller area to be high enough that the 3 original basins should have taken 50 cfs. This indicates the size of the pond footprint and its interactions with the underlying water table (mounding) likely has an influence on recharge rates.

The three recharge ponds (2004-5 through 2007-8) have a combined infiltration area of 1.1 acres. It does appear that during this period that the recharge rate is declining particularly from the first data point to the second. This may also be due to the accumulation of sediment through the operation at the site. A similar decreasing recharge rate trend also appears to be seen after the Phase III expansion, where recharge rate dropped from 12.0 cfs to 10.7 cfs.  This is a lower average recharge than when the site was 1.1 acres in total size.  However, as mentioned earlier in this section the staff operations of the intake relative to the white ditch, also may be playing a role influencing these values. Following this analysis, we weighted each of the recharge rates by total infiltration area (average recharge rate/infiltration area) and plotted the results in **Figure** 29. This helps to highlight that if surface area were the only thing to consider. It would appear that the benefits of increasing size to increase recharge rates likely plateaus somewhere between 0.34 acres and 1.1 acres, 38.3 cfs and 14.5 cfs respectfully. However the fact that infiltration rates do appear to drop when infiltration area is held constant indicates that surface area does not dictate infiltration rates alone.

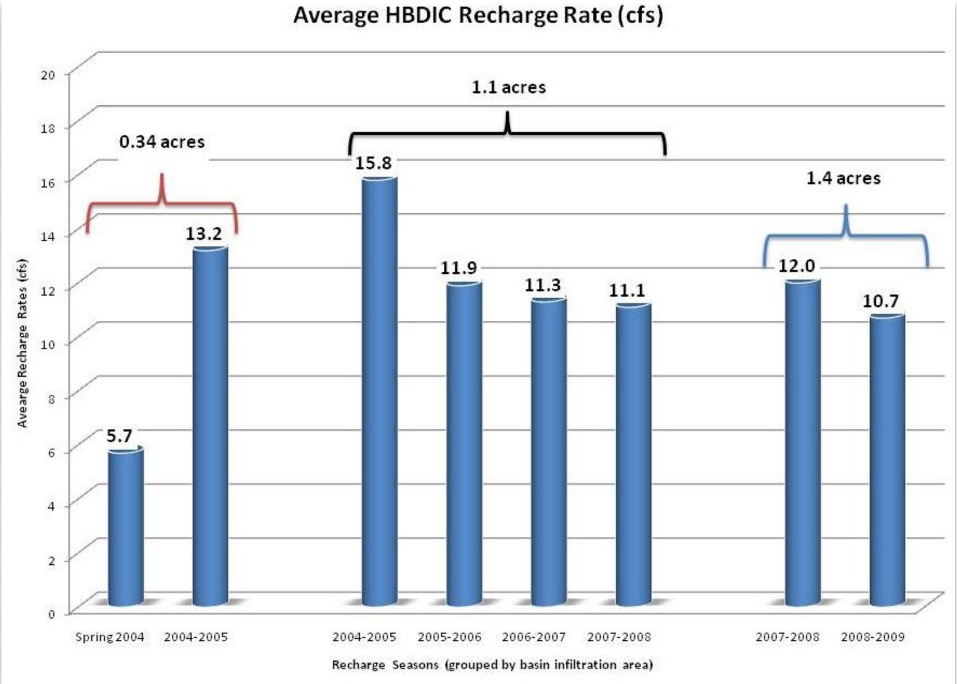


**Figure 28. HBDIC *Effective* Recharge rates (cfs) – 2004-9**

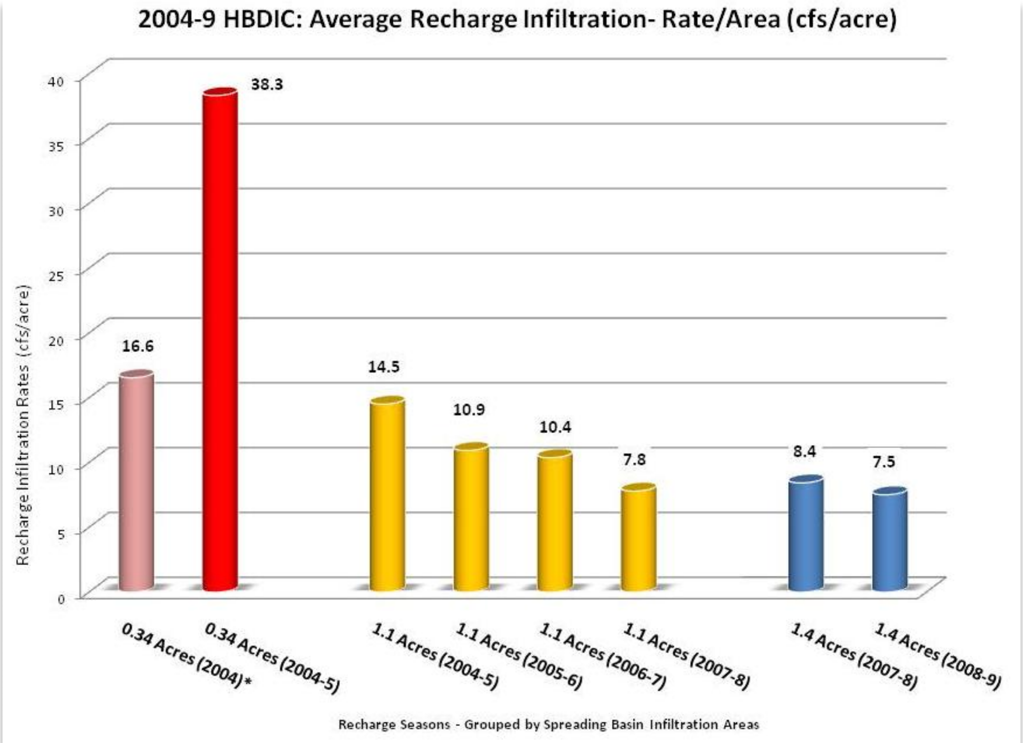


**Figure 29. HBDIC Recharge Rates in Acre-feet/day**

Mounding of the water table below the site could also be influencing these rates over time. The mounding below the recharge project happens due to the manner which water leaves the site and moves through the unsaturated (vadose zone) to the saturated (water table) subsurface zones. Water moving directly out of the bottom of the basin toward the water table moves quicker due to gravity and unsaturated conditions (**Figure** 30). Once that water mingles with the water table it slows down because then its only direction of movement is down gradient which is expressed by Darcy's law[17]; including permeability and pressure gradient (P) or more simply, slope of the unconfined water table. Because this rate of movement is slower than the vertical movement through the unsaturated zone, water tends to back up and "mound" upward toward the spreading basins. This water then begins to influence the rate at which water can infiltrate from the site.  Relative to the data being presented here, this would likely manifest itself in reduced infiltration rates even with increased infiltration areas.

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[17] In fluid dynamics and hydrology, Darcy's law is a phenomenologically derived constitutive equation that describes the flow of a fluid through a porous medium. Henry Darcy, *Les Fontaines Publiques de la Ville de Dijon* ("The Public Fountains of the Town of Dijon"), Dalmont, Paris (1856)

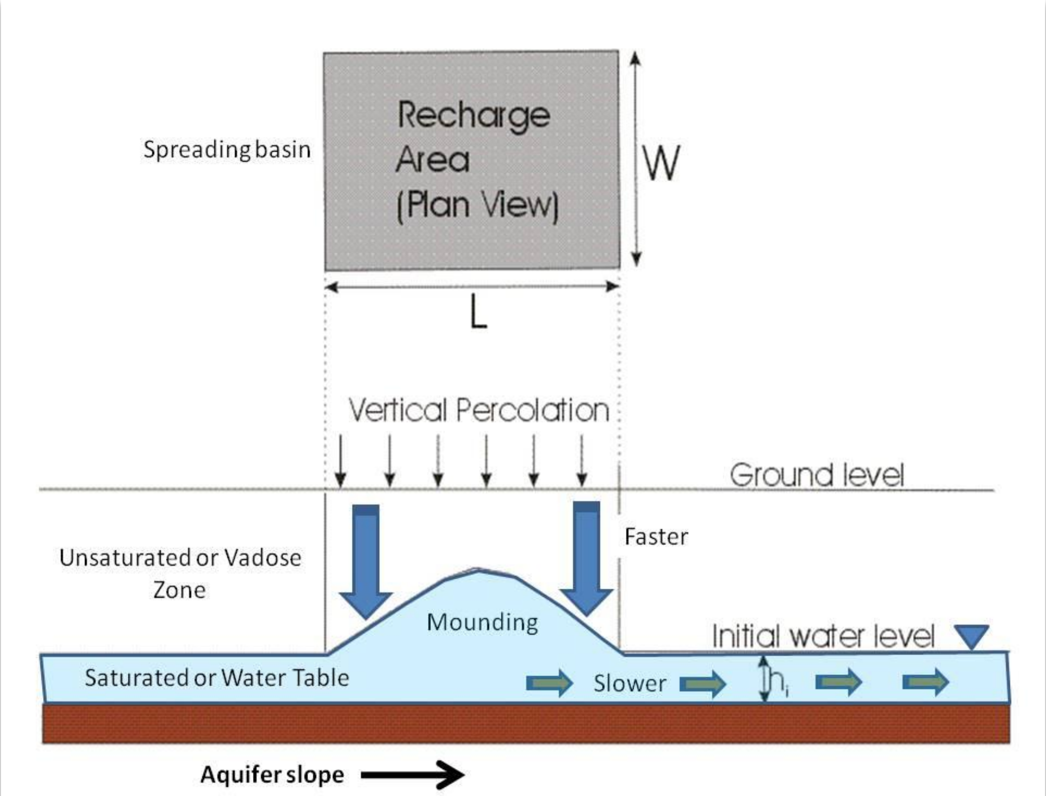


**Figure 30. Conceptual Diagram of Aquifer Recharge Mounding and Saturated Groundwater Movement**

Mounding could affect recharge rates over time if the HBDIC site was having the net effect of decreasing the distance between surface infiltration basins and the water table. In other words, if the HBDIC project through its six seasons of operations was having the net effect of localized aquifer recovery this could be expressed on the surface as decreasing *effective* recharge rates. **Figure** 31 shows one of the 4 on-site HBDIC monitoring wells (GW-45) and a seemingly increasing peak and trough recovery since recharge operations began.  Due to localized aquifer pumping, the operations of the White Ditch and other potential up gradient influences on the water table, it is difficult to clearly use this graph to conclude a recovery. However, it does provide some insight into the possible reduction in overall average *effective* recharge rates at the site and as more years of operations occur, the trend may become even more conclusive.

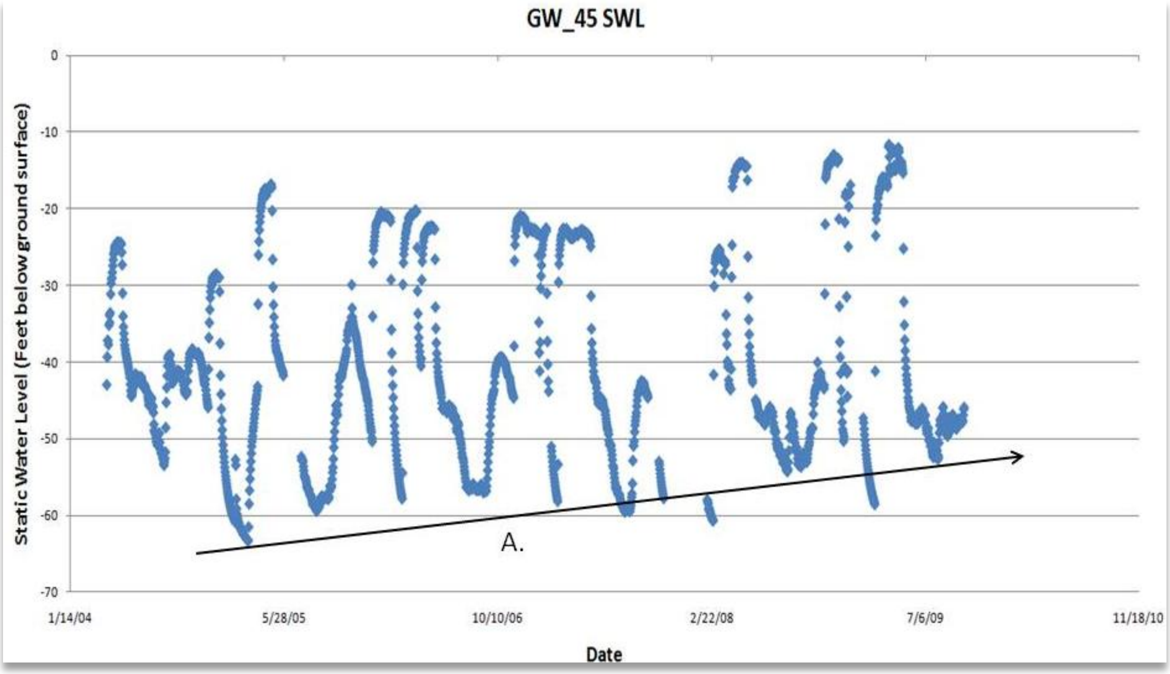


**Figure 31. HBDIC On-site Observation Well Water Level Data (2004-9)**

## HBDIC Water Quality Monitoring Program and Procedures (2004-2009)

The HBDIC Recharge Project represented the first project to apply for a limited testing license for aquifer recharge in the State of Oregon. With this, a concise water-quality sampling plan was developed during the project. Monitoring and ensuring that water quality is adequate to operate an aquifer recharge project was and continues to be a top priority for the HBDIC-WWBWC project team. Starting in 2003 Phil Richardson at Oregon Department of Environmental Quality (Pendleton, Oregon) along with Thomas Darnell at Oregon State University Extension (Milton-Freewater, Oregon) worked with WWBWC staff to develop the water quality parameters and testing protocols for the HBDIC project. This was completed during the original Limited Testing License application process in 2003-4. For more information on how this site-specific water quality monitoring plan for aquifer recharge was compiled, details can be found in *Hudson Bay Aquifer Recharge Project: An application for ASR Testing Limited License to Oregon Water Resources Department (OWRD) (OAR 690-350-0020), and attachments* (Bower R. J., 2003).

Since the original conception of the water quality plan, there have been a variety of progressive changes to the original plan. Working with ODEQ, the HBDIC-WWBWC team has adaptively modified the water quality monitoring to prioritize the analytes based upon collected samples and subsequent results. This has allowed the project to move from a fairly high-intensity sampling plan to a reduced, but focused list of key parameters. In some cases the analytes that were of most interest (mainly due to historic or current basin use) were not available from the HBDIC site laboratory contractor. Cindy O’toole at Edge Analytical worked with the HBDIC-WWBWC team to create laboratory standards for those analytes. In 2006 the original EPA SOC list was downsized to focus on priority analytes. Some of the new standards that ODEQ was most interested in were added. As of the 2009-10 seasons, the list discussed below is the current water-quality parameter list. To summarize the program and the results from the past water quality monitoring, it is best to separate sampling into two categories of constituents.

**Baseline Chemistry:**

- nitrate
- total kjeldahl nitrogen (TKN)
- total dissolved solids (TDS)
- chemical oxygen demand (COD)
- chloride
- orthophosphate
- fecal coliform bacteria

**Soluble Organic Compounds – Pesticides**

(Common/Trade names, EPA Drinking Water Method)

- 2,4 D acid, Dacamine, 515.1
- Dimethoate, Cygon, 525.2
- Metalaxyl, Ridomil, 525.2
- Napropamide, Devrinol, 525.2
- Simazine, Princep, Aquazine, 525.2
- 1-Naphthaleneacetamide, Amid-thin 525.2
- Diazinon, Diazinon, 525.2
- Fenarimol, Rubigan, 525.2
- Lindane, Lindane, 525.2
- Methidathinon, Supracide, 525.2
- Mevinphos, Phosdrin, 525.2
- Myclobutanil, Systhane, Rally 525.2
- Triflumizole, Procure, 525.2
- Azinphos-methyl, Guthion, 525.2
- Carbaryl, Sevin, 531.1
- Chlorpyrifos, Dursban, Lorsban, 525.2
- DDD (TDE) Rhotane, DDD, 525.2
- DDE degradation product, 525.2
- DDT Anofex, Gesarol, 525.2
- Dicofol , Kelthane, 525.2
- Malathion, Cythion, 525.2
- Methyl Parathion, Penncap, 525.2
- Phosmet, Imidan, 525.2
- Propargite, Omite, Comit, 525.2
- Triadimefon Dimethoate, Bayleton, 525.2

- Oxamyl, Vydate, 531.1
- Hexazinone DPX 3674, Pronone, and Velpar, 525.2
- Parathion-Ethyl, Niran, Phoskil (56), 525.2

The WWBWC has a ODEQ approved Quality Assurance and Quality Control plan that requires at least 10% repeatability on all water quality and temperature sampling. Therefore, for all of the sampling completed at the HBDIC site, additional samples are collected for QA/QC. Edge Analytical Laboratory Inc. a certified laboratory in Burlingame, Washington, performed the basic chemistry and soluble organic compound analysis under their laboratory QA/QC plan. Their results are shared along with 2004-9 sampling results in Appendix **I**. Fecal coliform and total coliform testing is done by the City of Walla Walla's Water and Waste Water Treatment facility in Walla Walla, Washington. They also have an internal QA/QC plan that controls the quality and repeatability of their procedures.

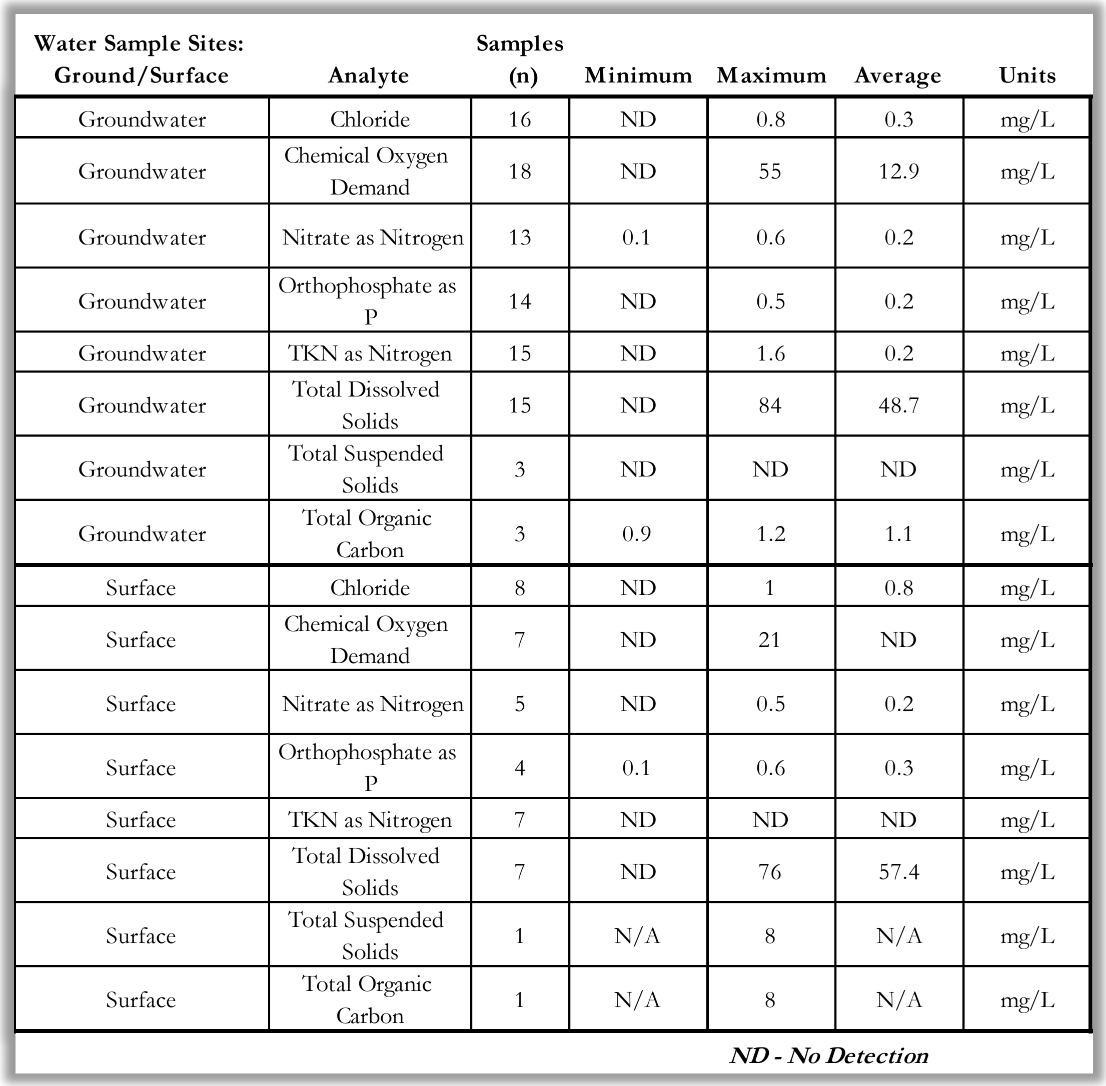
In the first several years of site operations Kuo Testing Laboratories staff collected water quality samples. WWBWC staff took over the field sampling effort in 2008. Source water samples are collected from the weir-channel on the intake structure, typically in the weir's small backwater eddy. Groundwater samples were originally collected using sterile eco-bailers from Observation Well #1 (GW-46). In 2006 the HBDIC-WWBWC team purchased a submersible pump specifically designed for evacuating several total volumes of the observation well before collecting the water quality sample. This was to ensure that samples represented ambient groundwater conditions and not those inside the well casing.

Upon collection, samples are immediately placed in ice filled coolers that are transported to either the City of Walla Walla's laboratory (fecal coliform samples) or a local over-night shipping company to be sent to Edge Analytical. Typically, the samples arrived at Edge Analytical in adequate time for them to be processed in the required holding time. Turnaround time for the results from either lab is dependent upon the parameter being analyzed. Fecal coliform and general chemistry are often fairly quickly completed, while SOC analyses typically takes the longest to process. All results are sent as paper and electronic copies to the HBDIC-WWBWC and the information is kept in our project database. In the event there is any detection that appears to be of concern, ODEQ staff in Pendleton is immediately notified via email and/or phone. Instructions on how to proceed are acted upon by HBDIC-WWBWC staff in a timely manner. More information on the annual sampling can be requested from the WWBWC staff through the website or by phone.

WWBWC staff also conducted additional water quality sampling for the infiltration gallery testing portion of the site. Samples are collected and analyzed for Total Suspended Solids (TSS) and Total Organic Carbon (TOC). These samples were collected to evaluate the rates of clogging that can influence the design and operations of these infiltration galleries.

### 2004-2009 HBDIC Recharge Water Quality Results

All of the original laboratory reports for HBDIC water quality sampling from 2004 through 2009 recharge seasons can be found in Appendix I of this document. Results include laboratory QA/QC, field notes and other pertinent information on the collection of this information over the six recharge seasons. For the 2004-9 recharge seasons the baseline chemistry for both the source and groundwater sites is summarized in Table 4. All values appear to be well within the maximum contaminant levels (MCL) for the state of Oregon. Surface water samples typically have slightly higher Chloride, Phosphate (ortho), Total Dissolved Solids (TDS), Total Suspended Solids (TSS) and Total Organic Carbon (TOC). The recharged groundwater samples tend to have slightly higher Chemical Oxygen Demand (COD) and TKN as Nitrogen; with Nitrates being about the same for both surface and groundwater samples.



| Water Sample Sites: Ground/Surface | Analyte | Samples (n) | Minimum | Maximum | Average | Units |
|---|---|---|---|---|---|---|
| Groundwater | Chloride | 16 | ND | 0.8 | 0.3 | mg/L |
| Groundwater | Chemical Oxygen Demand | 18 | ND | 55 | 12.9 | mg/L |
| Groundwater | Nitrate as Nitrogen | 13 | 0.1 | 0.6 | 0.2 | mg/L |
| Groundwater | Orthophosphate as P | 14 | ND | 0.5 | 0.2 | mg/L |
| Groundwater | TKN as Nitrogen | 15 | ND | 1.6 | 0.2 | mg/L |
| Groundwater | Total Dissolved Solids | 15 | ND | 84 | 48.7 | mg/L |
| Groundwater | Total Suspended Solids | 3 | ND | ND | ND | mg/L |
| Groundwater | Total Organic Carbon | 3 | 0.9 | 1.2 | 1.1 | mg/L |
| Surface | Chloride | 8 | ND | 1 | 0.8 | mg/L |
| Surface | Chemical Oxygen Demand | 7 | ND | 21 | ND | mg/L |
| Surface | Nitrate as Nitrogen | 5 | ND | 0.5 | 0.2 | mg/L |
| Surface | Orthophosphate as P | 4 | 0.1 | 0.6 | 0.3 | mg/L |
| Surface | TKN as Nitrogen | 7 | ND | ND | ND | mg/L |
| Surface | Total Dissolved Solids | 7 | ND | 76 | 57.4 | mg/L |
| Surface | Total Suspended Solids | 1 | N/A | 8 | N/A | mg/L |
| Surface | Total Organic Carbon | 1 | N/A | 8 | N/A | mg/L |

***ND - No Detection***

**Table 4. Summary of Baseline Chemistry Sampling Results (2004-9)**

During the 2004-9 sampling period there were only two Soluble Organic Compounds (SOC) detections at the HBDIC recharge site... Di (ethylhexyl)-phthalate was detected in observation well #1 at 2.2 ug/L on April 13, 2004. The 2004 EPA Maximum Contaminant Level (MCL) value for this compound is 6.0 ug/L. HBDIC-WWBWC monitoring staff working with ODEQ concluded that this was possibly a low-level detection arising from the newly installed PVC observation-well casing or possibly the well sampling equipment. The substance was never detected again at the site; however the HBDIC WQ monitoring strategy continues to include this analyte in the sampling routine. The only other detection was 3.2 ug/L of Bisphenol-A at HBDIC Observation well #1 on May 27, 2009. Bisphenol-A is not listed by EPA as having a MCL value but has recently been in the national media associated with concerns over the chemicals widespread use in water bottles and other plastic containers. The HBDIC-WWBWC team continues to monitor for this analyte but are unclear as to its source, whether from the site or in the laboratory equipment.

Table 5 provides a statistical summary of the results of the fecal coliform analyses taken at both the surface and groundwater sites from 2004-9. Surface water samples averaged between 0 to 39 MPN/100 ml from 2004-9 while groundwater showed much lower averages of 0.8 to 3.8 MPN/100 ml. During the first two recharge seasons additional fecal coliform and total coliform samples were collected in order to clarify the extent to which the HBDIC sample results were controlled by ambient conditions. Those results and discussion were shared in the 2004 (Bower R. , 2004) and 2004-5 (Bower R. , 2005) reports which can be found by contacting the WWBWC. In summary, due to the widely distributed extent of low level fecal contamination, it was determined that the detected fecal coliform was considered an ambient background condition; and was not a result of HBDIC recharge site operations.

| | Surface | | | Groundwater | | | |
|---|---|---|---|---|---|---|---|
| Sampling Year | Minimum | Maximum | Average | Minimum | Maximum | Average | Units |
| 2004 | 1 | 130 | 39.8 | 0 | 14.8 | 3.8 | MPN/100 ML |
| 2004-5 | 0 | 62 | 9.4 | 0 | 12 | 2 | MPN/100 ML |
| 2005-6 | 14 | 20 | 17 | 0 | 3 | 1 | MPN/100 ML |
| 2006-7 | 7 | 23 | 15.3 | 0 | 3 | 1 | MPN/100 ML |
| 2007-8 | 11 | 14 | 12.5 | 0 | 1 | 0.5 | MPN/100 ML |
| 2008-9 | N/A | 19 | N/A | 0 | 2 | 0.8 | MPN/100 ML |

**Table 5. 2004-9 Fecal Coliform Bacteria Sampling Statistical Summary of Results**

## Indicators of Soil-aquifer Treatment (SAT) at the HBDIC Recharge Site

Through the work of Dr. Herman Bouwer and others in the field of infiltration-basin aquifer recharge, the concept of natural attenuation of source water entering the groundwater through unsaturated soil has been formulated. Bouwer summarized the surface to subsurface process as:

> *"Where soil and groundwater conditions are favorable for artificial recharge of groundwater through infiltration basins, a high degree of upgrading can be achieved by allowing partially-treated sewage effluent to infiltrate into the soil and move down to the groundwater. The unsaturated or "vadose" zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses, and other microorganisms. Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved."* (Bouwer, 1987)

While the source water entering the HBDIC site is not “sewage effluent” the process of bacteria and other pollutants being stripped from the water as it moves through the unsaturated zone is worthy of further review. When reviewing the data collected at the HBDIC recharge site, the parameter that is most likely to benefit from this process is ambient (but prevalent) fecal coliform contamination. During the initial start-up sampling of each recharge season, source and recharged water samples were collected. The results, when compared statistically, seem to indicate that natural attenuation is occurring at the site. **Figures** 32 and 33 show an order of magnitude lower fecal coliform concentration (average 2.7 MPN/100 ml) in the recharged groundwater than in the recharge source water (28.3 MPN/100 ml).

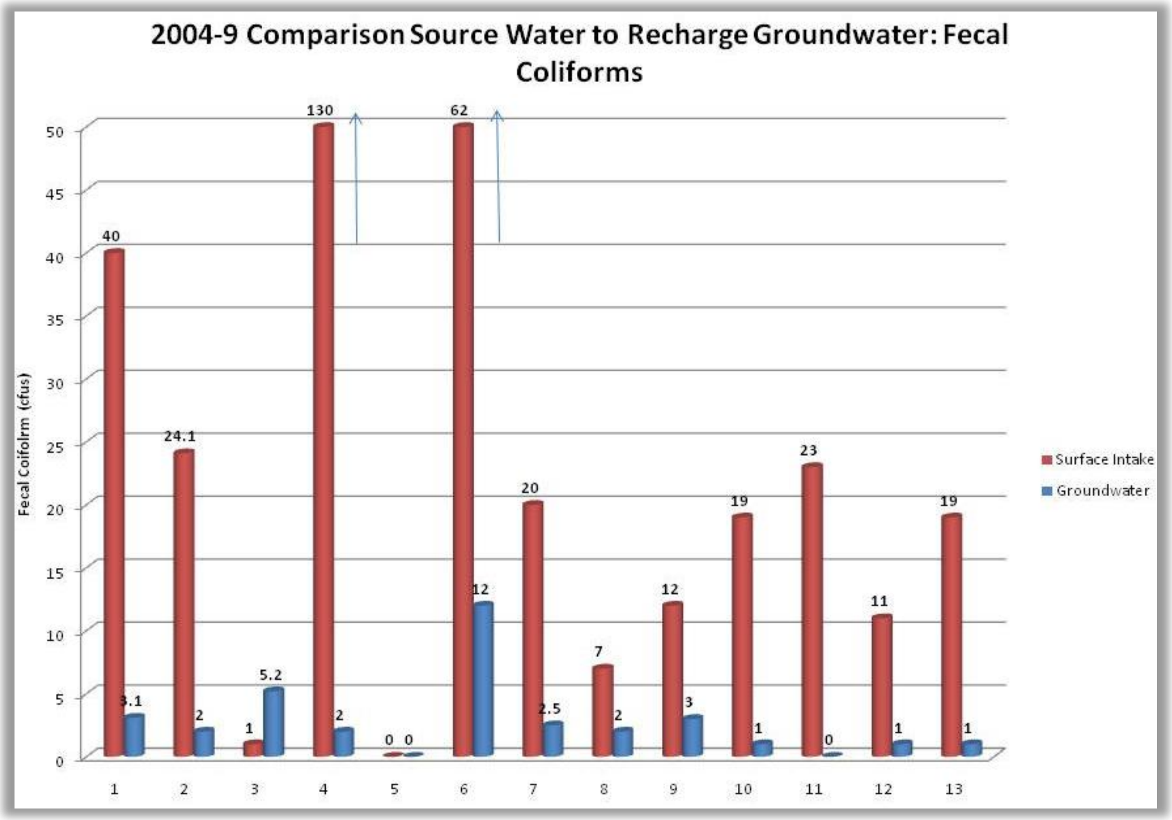


**Figure 32. Surface versus Groundwater Fecal Coliform Results (2004-9)**

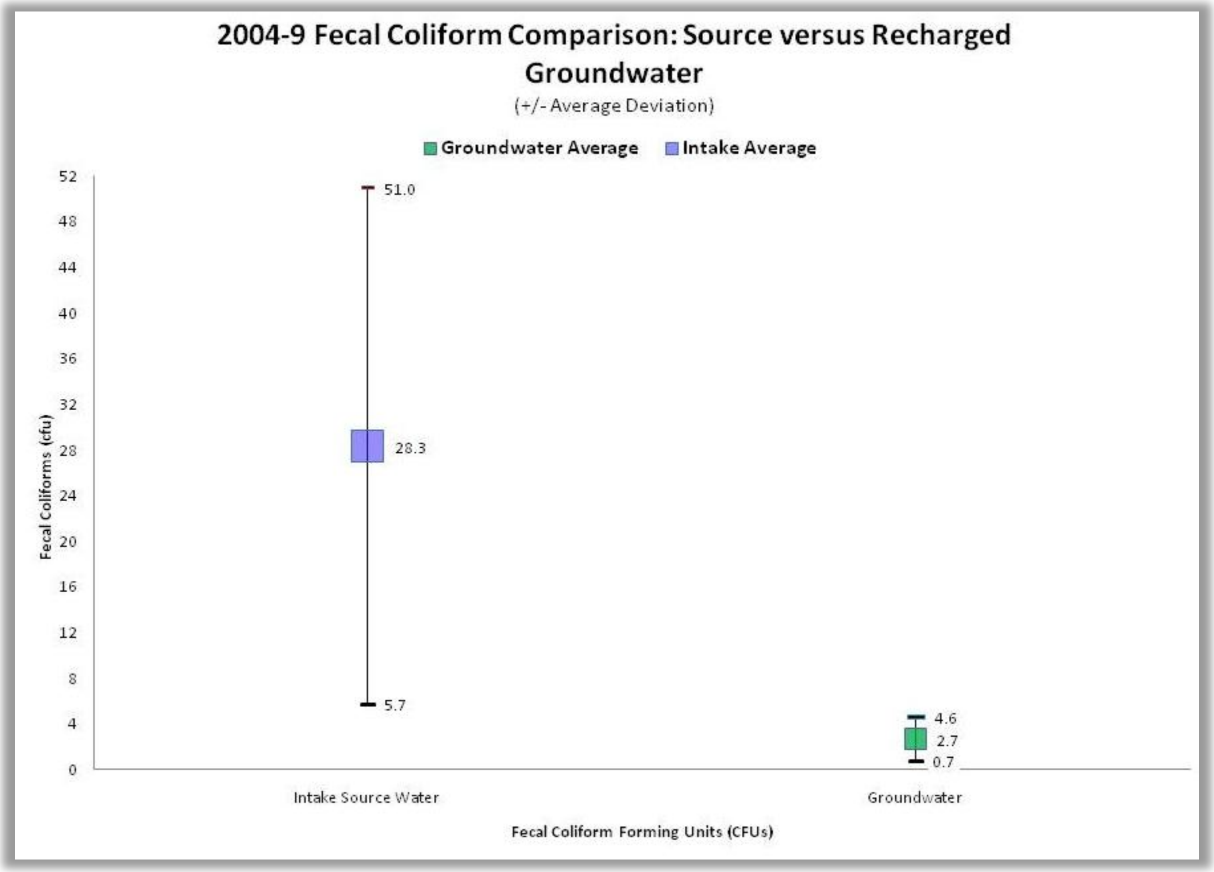


**Figure 33. Comparison of Source vs. Groundwater fecal coliform statistics (2004-9)**

Enteric bacteria like fecal coliform arise from the intestines of animals and are an indicator of more harmful pathogens in our water supplies. They have a limited range of temperature at which they can survive, usually corresponding to their host organism's body temperature (e.g. humans $37^0$ C). While more sampling would be required to determine a more statistically robust conclusion, this does seem to correspond to literature supporting the process of source water quality improving through natural attenuation during aquifer recharge. This may help water quality regulators in the permitting future aquifer recharge projects.

## Aquifer Response to Recharge

The purpose of aquifer recharge for the Walla Walla basin is to help stabilize and recover the shallow aquifer's groundwater storage supplies. Increased groundwater storage means historic springs that have experienced diminished flow could recover and flow again to the Walla Walla River- providing enhanced flow and off-channel habitat for recovering salmonids. In addition, increased groundwater storage would result in increased potential returns from the shallow aquifer to the Walla Walla River, helping to support and protect base flow - particularly during the low-flow months. Monitoring an aquifer recharge project, in order to document its contributions toward this overall aquifer recovery purpose, can be broken down into two main scientific questions:

1. Did the aquifer respond to aquifer recharge operations?
2. Did the springs respond to changes in aquifer conditions from recharge operations?

This section focuses on tracking the process of aquifer recharge from the site out through the groundwater system; then intends to document the connection between those responses seen in the groundwater to those expressed in the springs. As the shallow aquifer system is large and complex, the focus of this section is limited to an area where recharge response is visually and graphically apparent. To demonstrate the overall benefits to aquifer storage, system wide recovery of springs and contributions to the Walla Walla River, the HBDIC-WWBWC team is relying on the IWFM modeling work[18] that Oregon State University will complete in mid-2010. Since the HBDIC likely represents only a small portion of the recharge 'need' in the alluvial aquifer system, it is not intended to show complete recovery of the aquifer. Understanding how much recharge and where to place it for maximum benefit, will be based on the scenarios generated by the IWFM model as well through the WWBWC's Bi-state Aquifer Storage and Spring Restoration program (ARSRP)[19].

## Site-Specific Groundwater Response

In order to track the aquifer response to HBDIC recharge operations, responses in on-site monitoring wells were reviewed. **Figure**s 34 and 35 illustrate the response of the four on-site monitoring wells (GW-45, GW-46, GW-47, and GW-48) to recharge operations during the 2008-2009 recharge seasons. These hydrographs are very typical of what was observed in previous recharge seasons.

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[18] IWFM modeling project funded by WDOE and OWEB in collaboration with the WMI Monitoring Program. Contact the WWBWC for more information.

[19] ARSRP is a bi-state recovery strategy that was the logical outcome from the aquifer recharge and WMI monitoring program lead by the WWBWC. For more information contact the WWBWC.

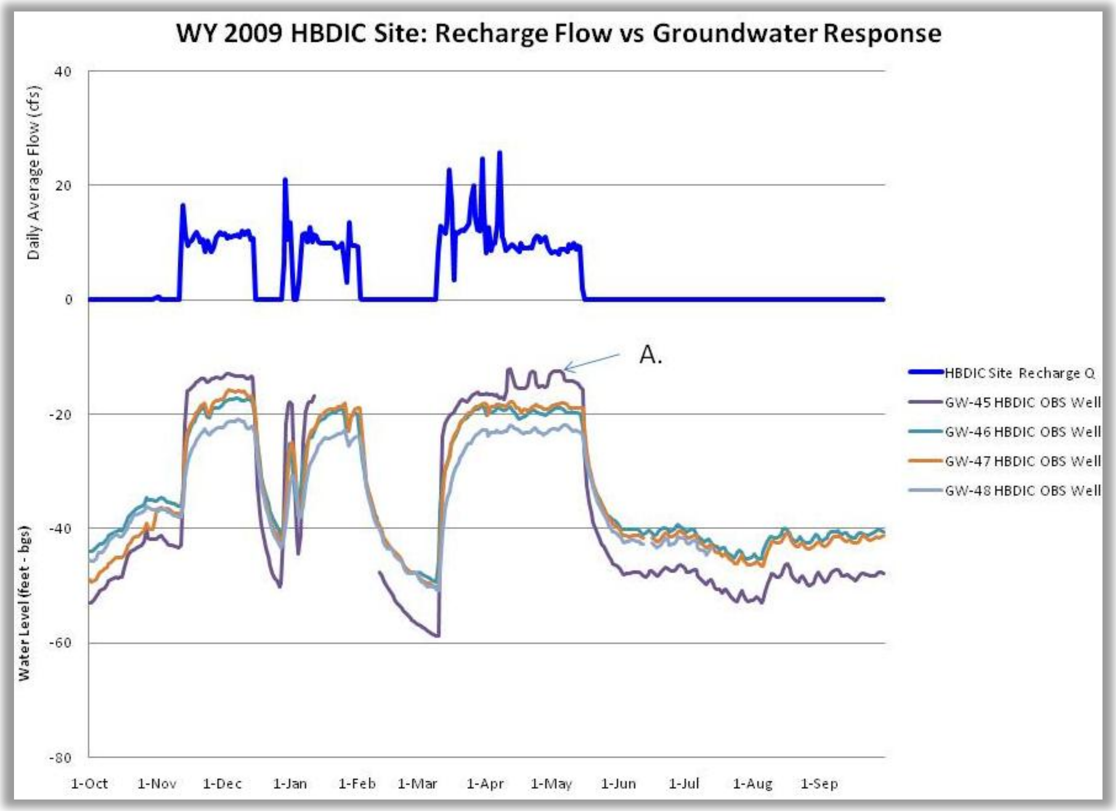


**Figure 34. On-site Surface to Groundwater Response to Recharge Operations (2009)**

**Figure** 34 shows the recharge flow rate (cfs) into the basins and the groundwater response to the recharge at the four on-site monitoring wells. It is clear that operations of the HBDIC recharge site have a direct mounding effect on the local water table. The staggered nature of the water levels in each of the wells is due to both their proximity to the mounding and their placement relative to the direction of groundwater flow. GW-45 now resides between the infiltration gallery and the down gradient spreading basins, which explain its higher overall water level. Also GW-45 shows the groundwater response (A.) to the 2008-9 infiltration galleries testing, which was done in 1-2 week blocks of operations.

**Figure** 35 shows GW-45 has the greatest response to operations. The up gradient well GW-40, which is ~10-15 feet from the White Ditch, also shows the influences of canal infiltration on the water table.

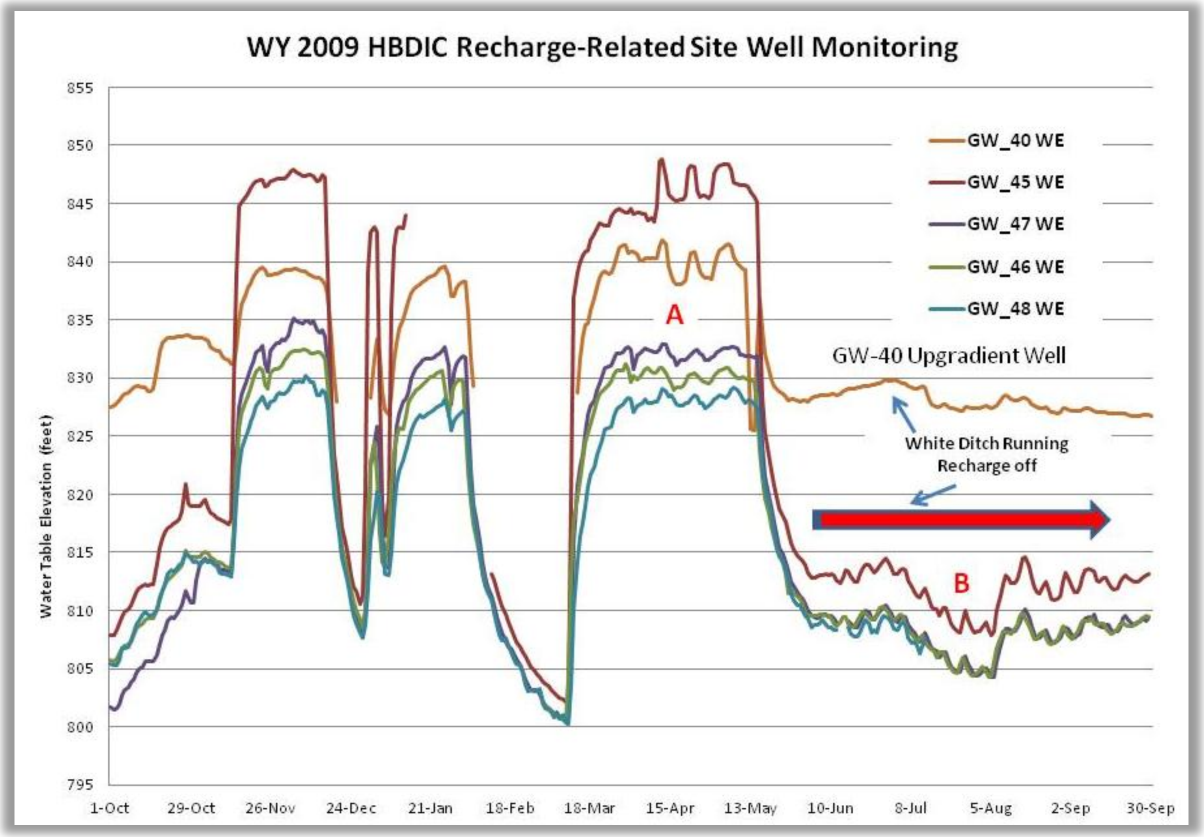


Figure 35. HBDIC Site Monitoring Wells and Various Sources of Recharge

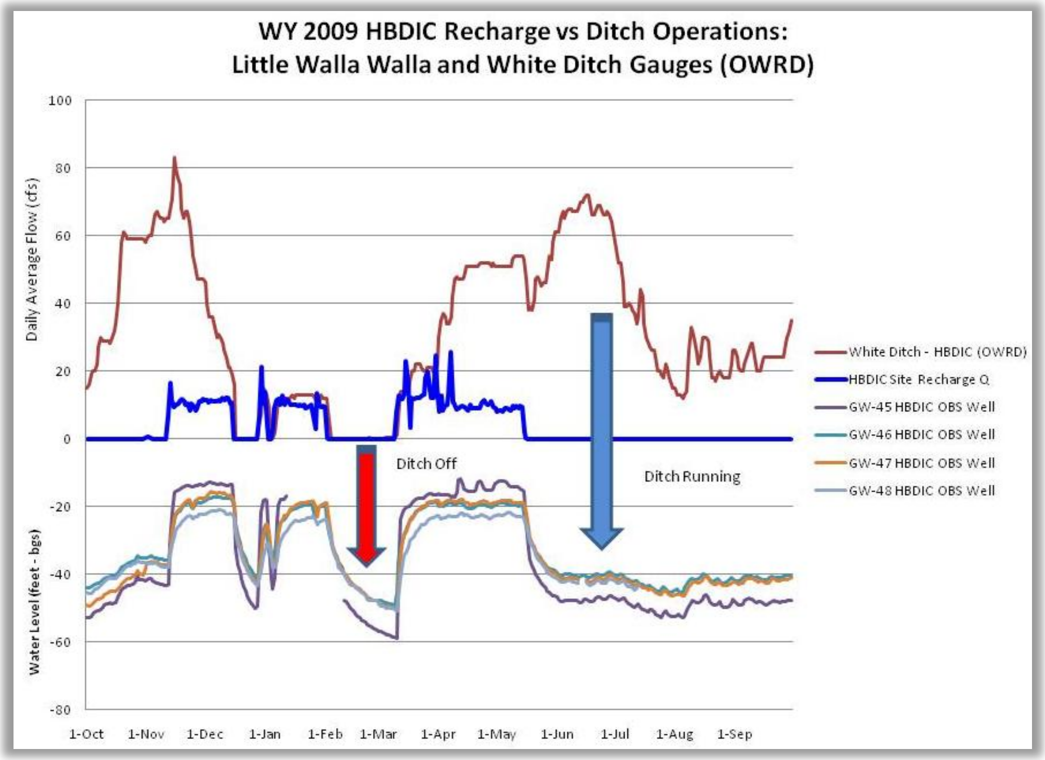


**Figure 36. Comparison of White ditch and HBDIC recharge site operations to Groundwater Response**

After the HBDIC recharge operations are turned off (May 15th), the HBDIC White Ditch continues operating into the late spring and early summer. In 2009 the system ran for the entire irrigation season due to an exceptional snow pack; however this is not typical of most years. **Figure** 36 illustrates the groundwater response to operation of the White Ditch (OWRD Gauge #) and HBDIC recharge site. When the White Ditch operation ceases the aquifer responds with declines in water level. Subsequently when the ditch is operating and HBDIC recharge is not occurring, the aquifer rises, to a higher level, which does appear to stabilize; suggesting an equilibrium between seepage and water level is reached. The data indicates that canals and ditch systems provide recharge water that if piped, will need to be replaced in order to achieve the purpose of aquifer stabilization and recovery.

Next, we shift our analysis to determine if there are any visible signs of water table recovery over the first 6 seasons of operations. **Figure**s 37 and 38, respectively, show groundwater levels (2004-9) during low flow periods and peak recharge periods. During the low-flow period (June 1st through September 30th) the recharge site is not operating but the White Ditch and surrounding groundwater pumping are underway. WY 2005 was a drought year during which surface water irrigation was drastically reduced due to lower than average Walla Walla River flows and additional groundwater pumping was done by many water users. Contrasting WY2005 to WY2009 (when strong Walla Walla River flow allowed HBDIC to operate the White Ditch for the entire summer) groundwater levels remained high. Conclusively determining groundwater recovery is difficult in this highly interconnected and volatile aquifer system, due to season by season changes in surface and groundwater conditions.

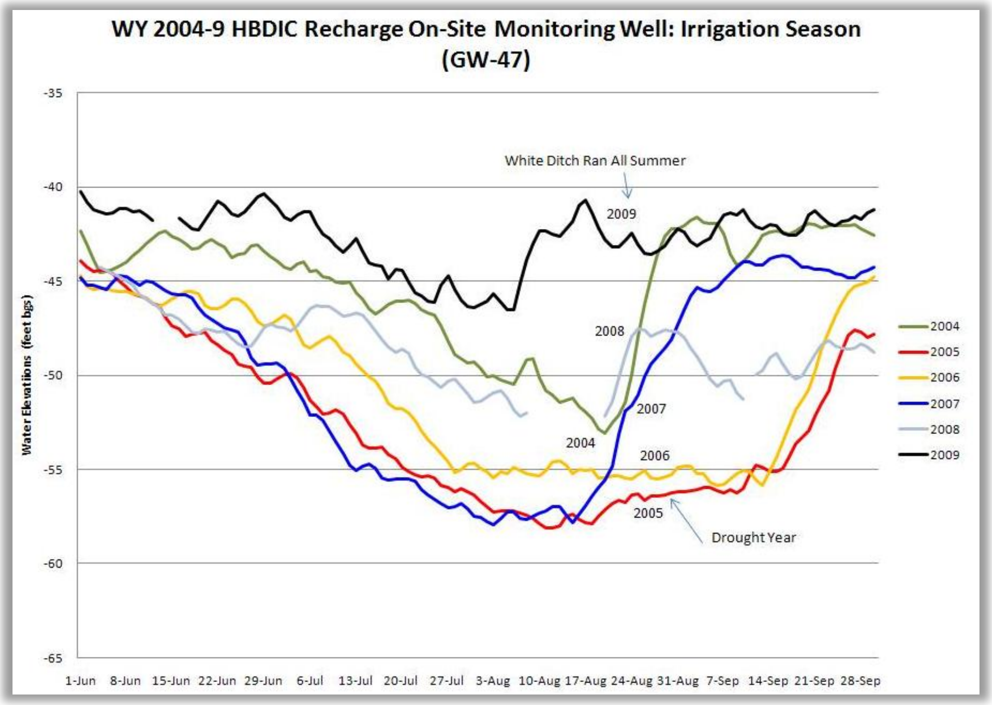


**Figure 37. HBDIC Site Observation wells Irrigation Season water levels (2004-9)**

Shifting the focus to the water table peak elevations when the HBDIC Recharge site is operating may indicate a general trend toward higher water table elevations at the site. While this could be tied to recovery of the localized water table it is also likely linked to the expanding infiltration area getting closer to the GW-45 well head. It appears there may be some correlation between rates of *effective* recharge and the height of the mounding at the site. Also it appears that the closer the infiltration area gets to this well higher water levels are observed. Further, investigations using this well and the horizontal distance to infiltration water may provide insights into actual depth to water mounding at the HBDIC site.

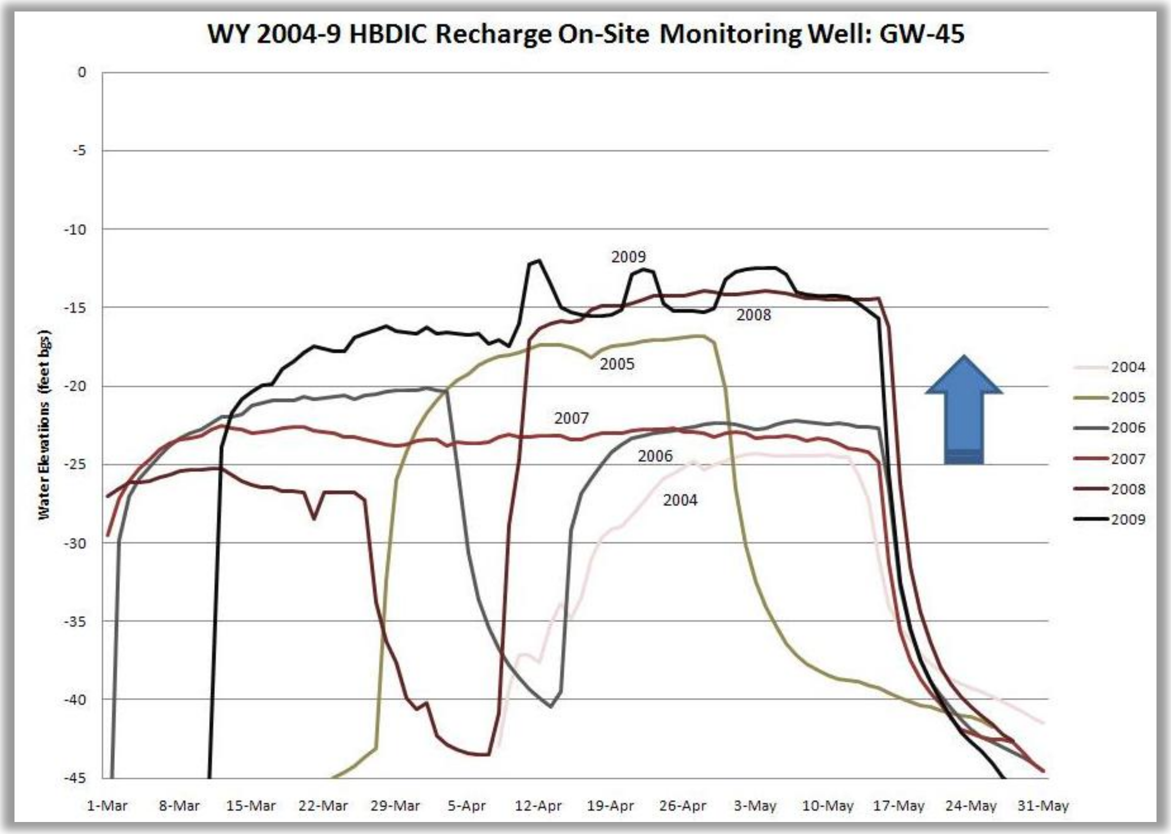


**Figure 38. Water Table Response to HBDIC Recharge Operations: May 1st- May 31st**

## System Wide Groundwater Response to Spreading Basin Operations

Starting in 2001 the WWBWC working with its partners at OWRD, WDOE and OWEB began to put together a bi-state well monitoring system through state and federal grant funding. The purpose of this system is to better document overall shallow alluvial groundwater conditions as well as monitor subsurface responses to water management activities such as aquifer recharge and ditch piping. When the program started there were approximately 11 OWRD observation wells in Oregon and 1 WDOE well in the Washington portion of the Walla Walla River Valley. As of 2010, there are over 110 wells in the WWBWC's Bi-state well monitoring system that include dedicated (**Figure** 39) and existing wells that are either instrumented for continuous data or measured quarterly for static water levels (Bower R. , 2009; Patten S. , 2009). **Figure** 40 shows the extent of the monitoring system and their placement relative to the alluvial aquifer system in the Walla Walla River Valley.

Figure 39. WDOE Funded Dedicated Observation Well at Pepper Bridge Vineyards Road Grange Hall (Washington)

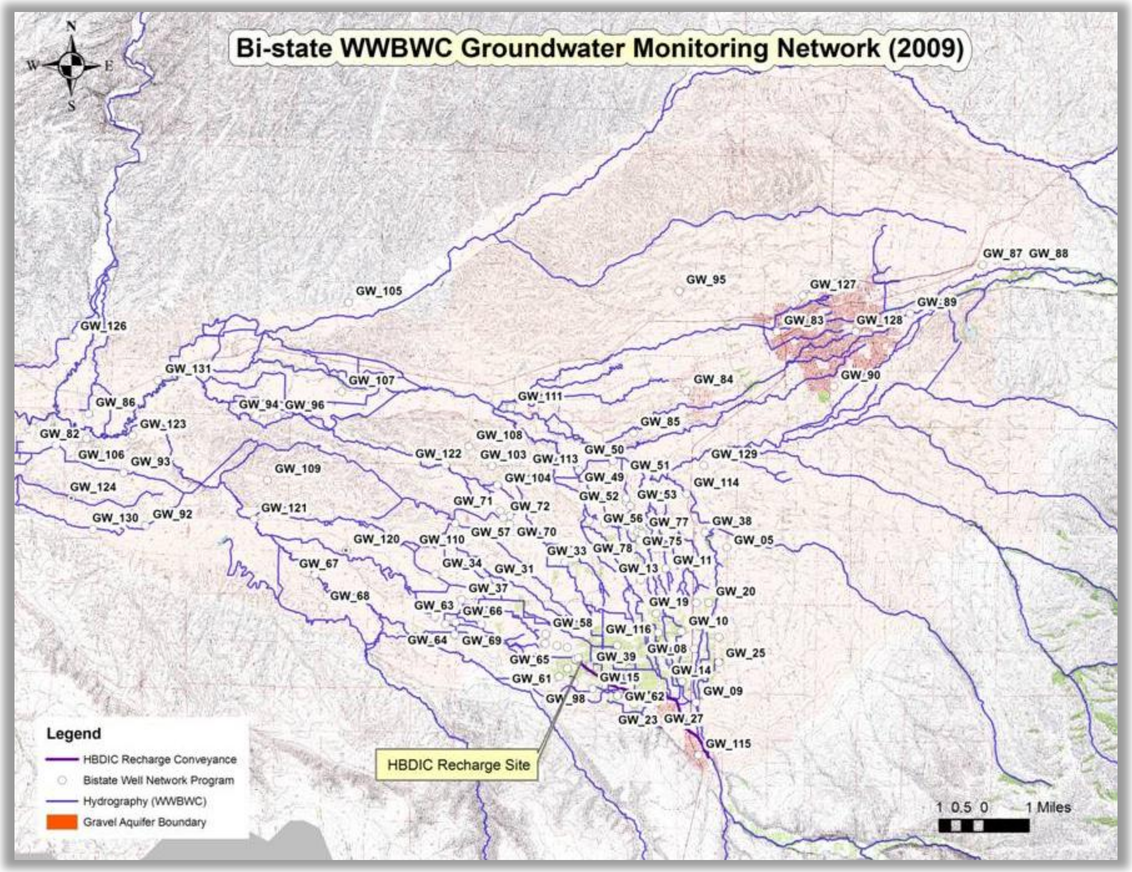


Figure 40. Map depicting WWBWC's Bi-state Well Monitoring System of the Walla Walla River valley Shallow Aquifer System

In the area interpreted to be down gradient of the Site water level data was examined to evaluate aquifer response, if any, to site recharge operations. By looking in the Johnson Creek area, we can focus on an area where recharge mounding more distally from the site should be seen in the water table response. To do this, several transects were selected. Moving up gradient from the HBDIC site, transect A on **Figure** 41 starts at the HBDIC up gradient control well GW-14 which shows no visible signs of HBDIC recharge activities. This well is directly underneath irrigated orchards near the Walla Walla River. Influences from irrigation are suggested by water level recovery during spring and summer irrigation activities. Additionally, GW-14 may show signs of decreasing groundwater levels in the Little Walla Walla River area (**Figure** 42). Transect A parallels the White Ditch that delivers the source water from the Walla Walla River to the HBDIC Recharge Site. The elevation difference along Transect A is from 910 (GW-14) to 817 feet (GW-40).

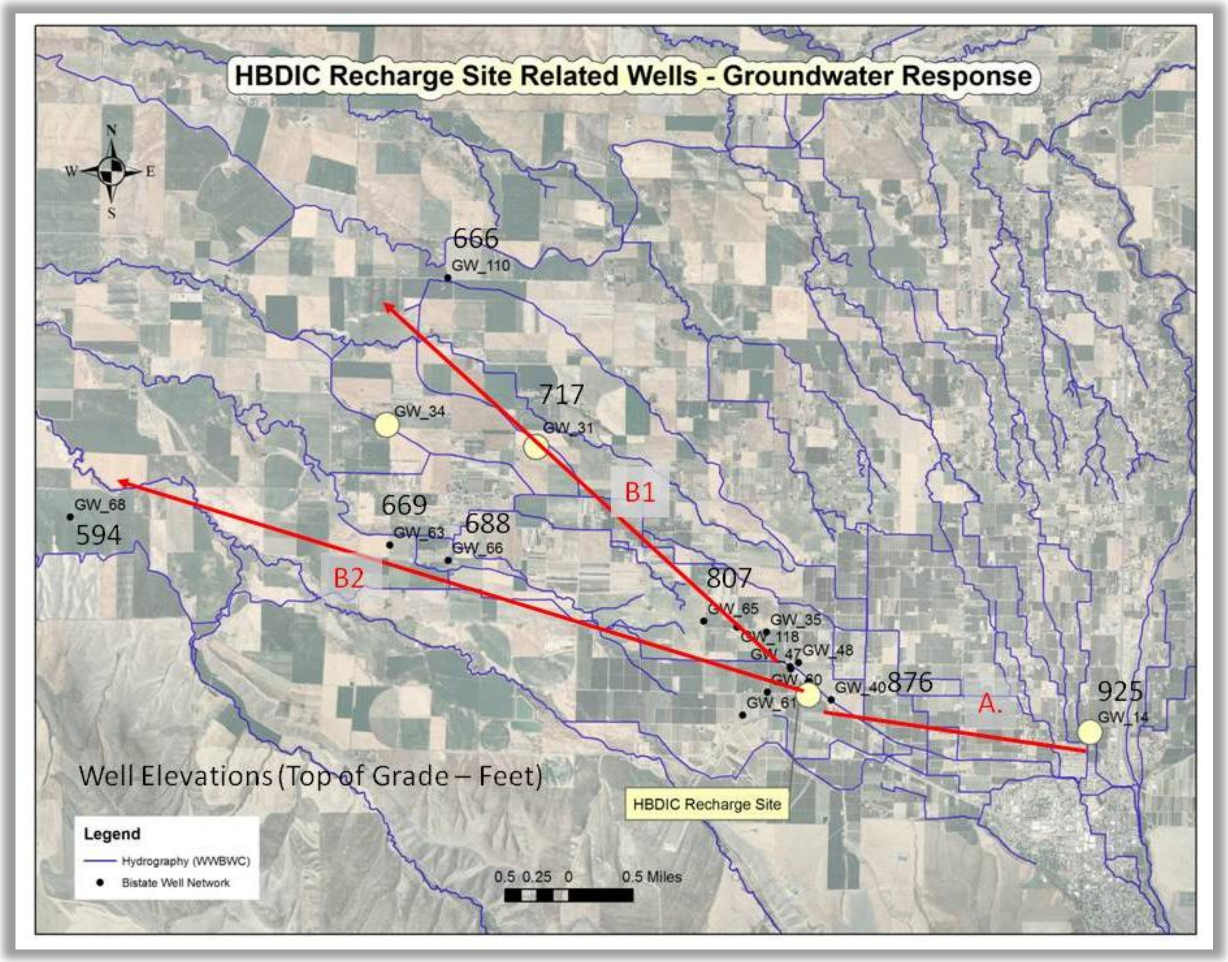


**Figure 41. WWBWC Monitoring Wells and Transects Relative Recharge System Response**

Moving down gradient from the HBDIC recharge project and GW-45 (**Figure** 41) two transects were selected in which to track groundwater response. An earlier 2005 HBDIC Recharge Site Monitoring report (Bower R. , 2005) documented the pressure wave from HBDIC recharge activities in wells in the Johnson and Dugger Spring-Creeks areas. Transect B1 generally follows the monitoring wells paralleling the Johnson Spring-Creek with transect B2 paralleling the Dugger Spring-Creek system. Monitoring wells GW-31 (**Figure** 43) and GW-34 (**Figure** 44) in the Johnson Creek sub-basin show indications of possible groundwater recovery albeit with the incomplete continuous dataset sets, it makes it more difficult to be conclusive. Note the arrow lines provided on each graph are for trend-visualization only and are not linear regressions of the data. This is an area where extensive piping has occurred in recent years (e.g. HBDIC's Richartz Ditch-to-Pipeline conversion) which would seem counter intuitive to what appears to be gradual groundwater recovery. Coupling these results with those of increasing water table levels at the HBDIC recharge site will be something to continue to monitor as the project progresses.

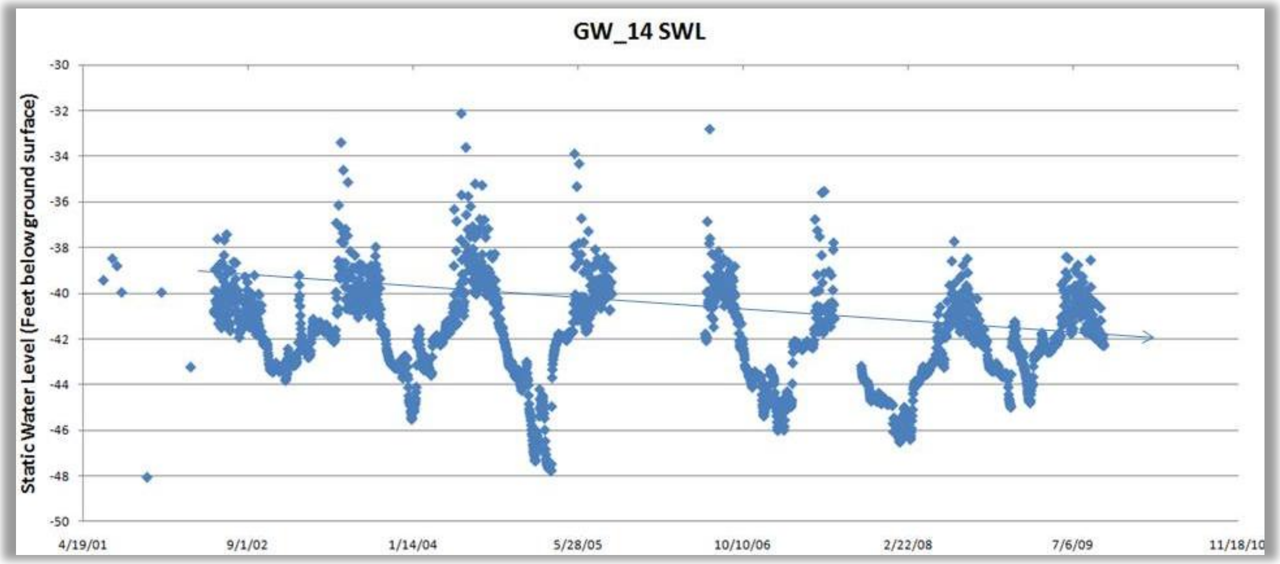


**Figure 42. WWBWC Dedicated Monitoring Well used as up gradient Control for HBDIC Recharge Groundwater Response (2001-9)**

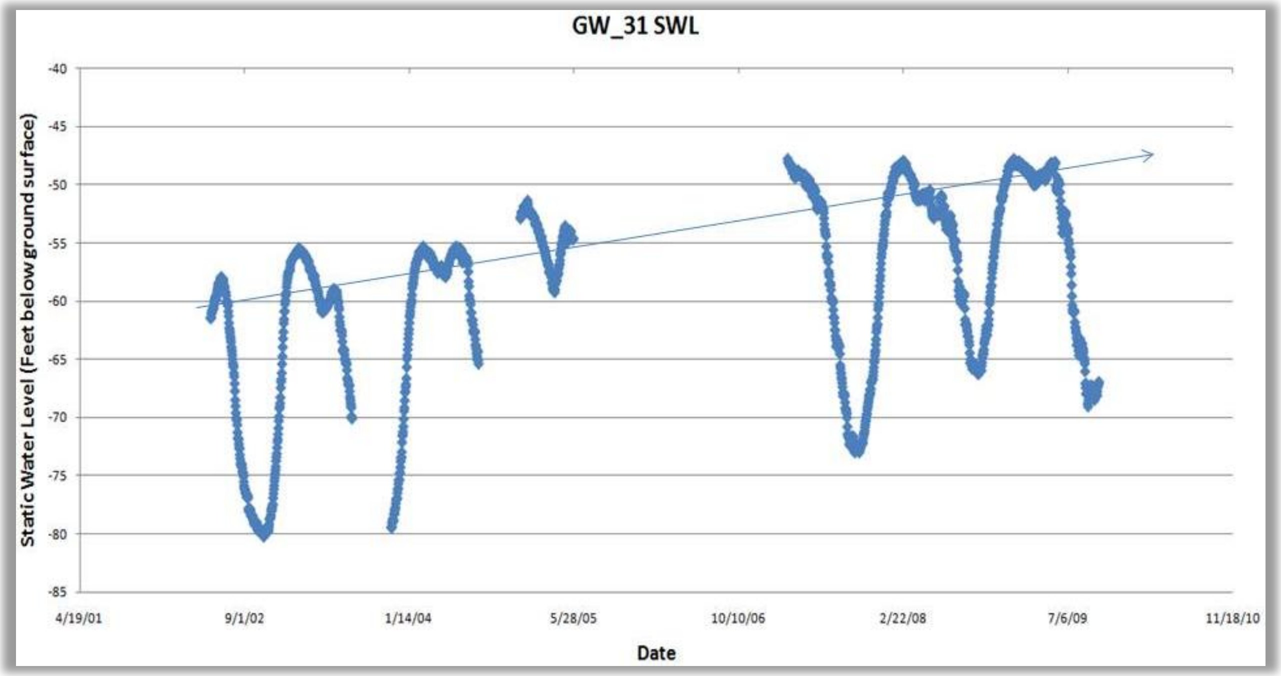


Figure 43. Water Levels at WWBWC Monitoring Well GW-31 (2002-9)

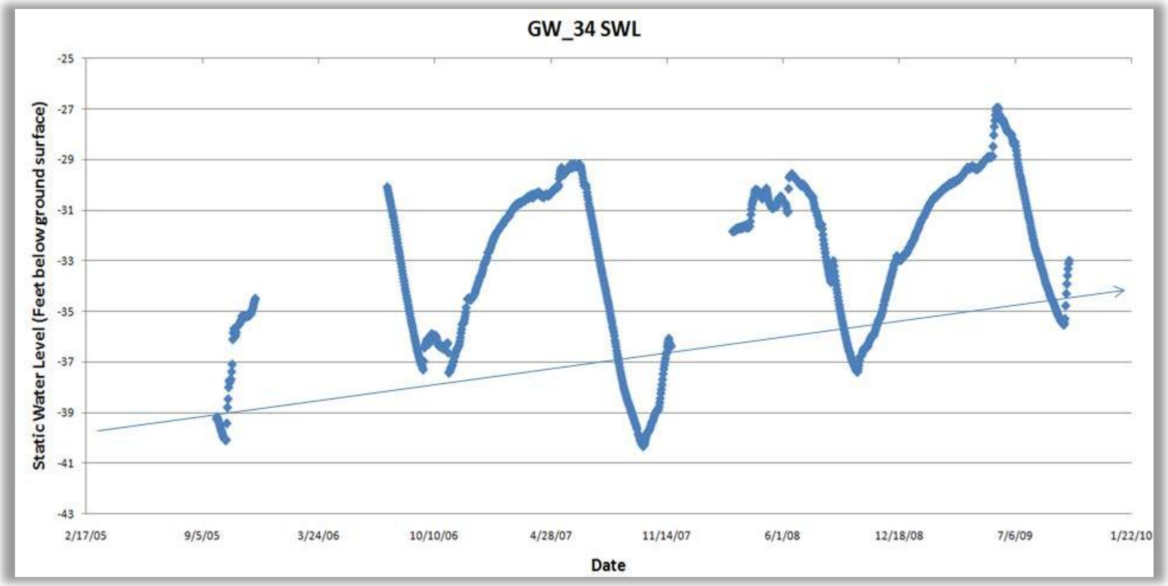


Figure 44. Water Levels at WWBWC Monitoring Well GW-34

Plotting all the groundwater elevation data for transects A to B1-B2 for water year 2009 (November 1st 2008 through September 30th 2009) helps show the spatial response of this area to HBDIC operations. **Figure** 45 clearly shows that GW-14 provides a representative up gradient control well for the purposes of documenting HBDIC operations. Wells GW-40, GW-45, GW-46 GW-48 representing the on-site HBDIC operations monitoring wells document the near-basin mounding effects of aquifer recharge. Down gradient and away from the site, wells GW-35, GW-118, GW-60, GW-61 and GW-65 show the height of the mounding decreases with horizontal distance. GW-65 clearly shows that by approximately one mile down gradient (GW-45 to GW-65), the mounding is still visually apparent.

Moving toward the outer boundary of the each of the transects B1 and B2, wells GW-110, GW-63, GW-31 all show an increase in head during the upgradient recharge operations (**Figure** 45). However, with numerous users of the HBDIC ditch also operating during this period of active infiltration from the project, recharge from up gradient water users and the Little Walla Walla River system likely plays a role in a portion of this recovery. From the extensive aquifer testing done at the project site OSU-WWBWC estimated groundwater velocity to be approximately 1 meter/day. This is significantly less than the measured response seen in the water table around the project as the project has turned on and off. The water table response to recharge changes propagates through the aquifer many times faster than the water actually moves. The next step in the process of linking recharge operations to directly helping to restore spring-creeks in the basin is to link these change in water table head to the changes in flow that occur at the down gradient springs.

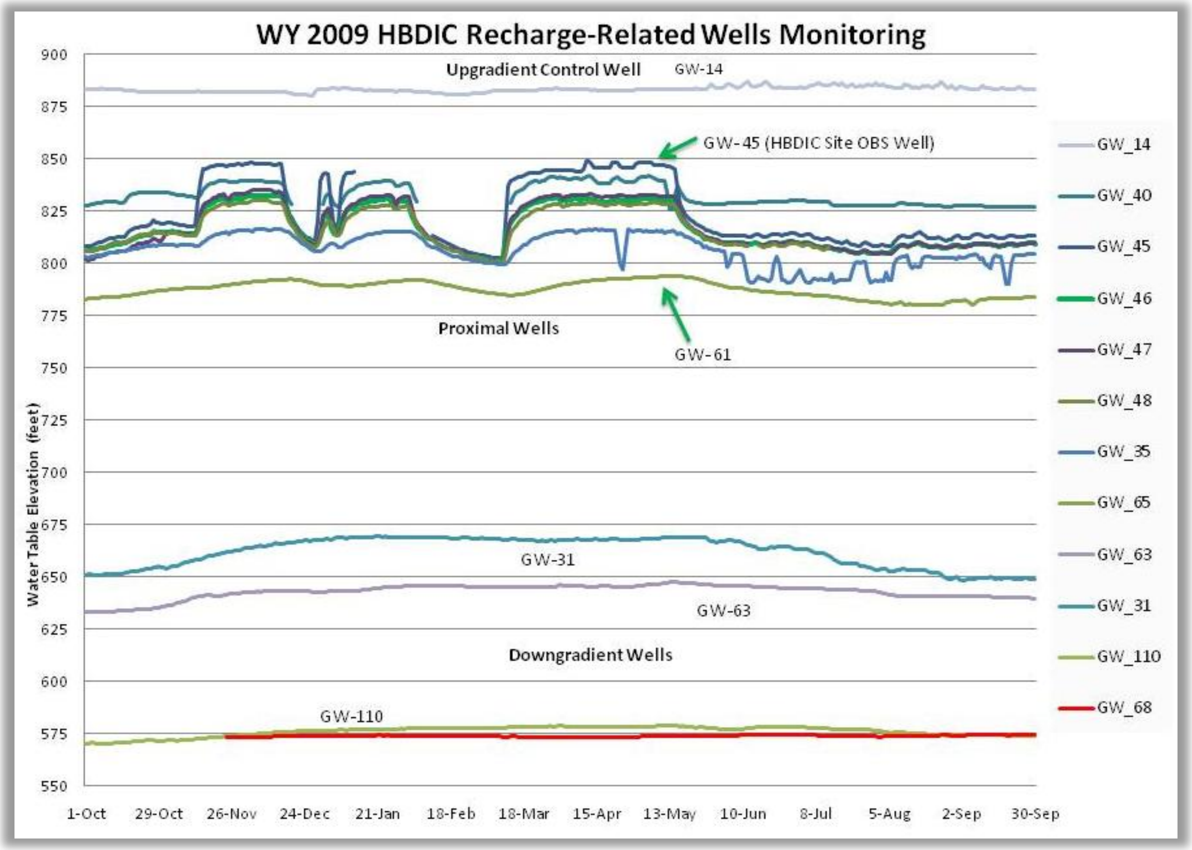


**Figure 45. Groundwater Response to recharge in Johnson and Dugger Spring-Creeks Subbasins (2009)**

A groundwater flow model is being constructed to assess groundwater responses to the HBDIC Recharge project, particularly overall groundwater storage and spring flow restoration. Utilizing finite-element IWFM modeling work by OSU (Petrides, 2008), WWBWC GIS water table mapping using data from the well network (Baker T. , 2010) and other USGS hydrologic studies and models, **Figure** 46 was created to show the water table contours and general flow direction relative to the HBDIC recharge site during September 2009. Generally groundwater flows in a west to northwest direction. Additionally, specific conductance (uS) collected from groundwater monitoring sites was assessed using Arch GIS Spatial Analyst to help depict groundwater movement (**Figure** 47). HBDIC recharge site shows lower values indicating the recharge of surface water at site and down gradient movement.

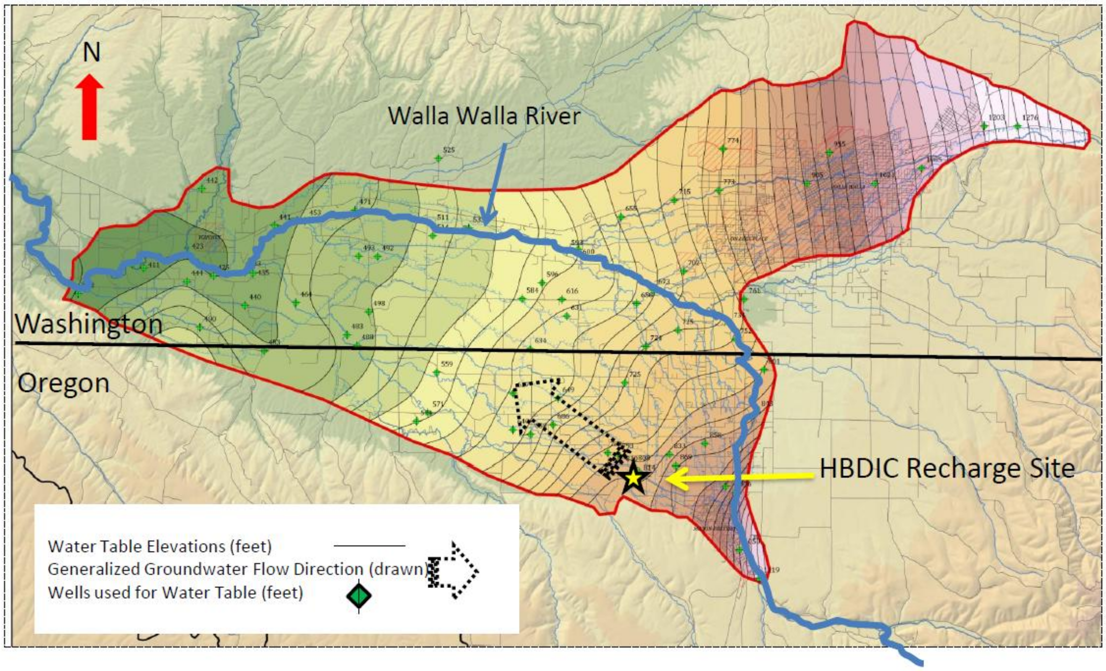


**Figure 46. HBDIC Recharge Site Flow Direction(September 2009)**

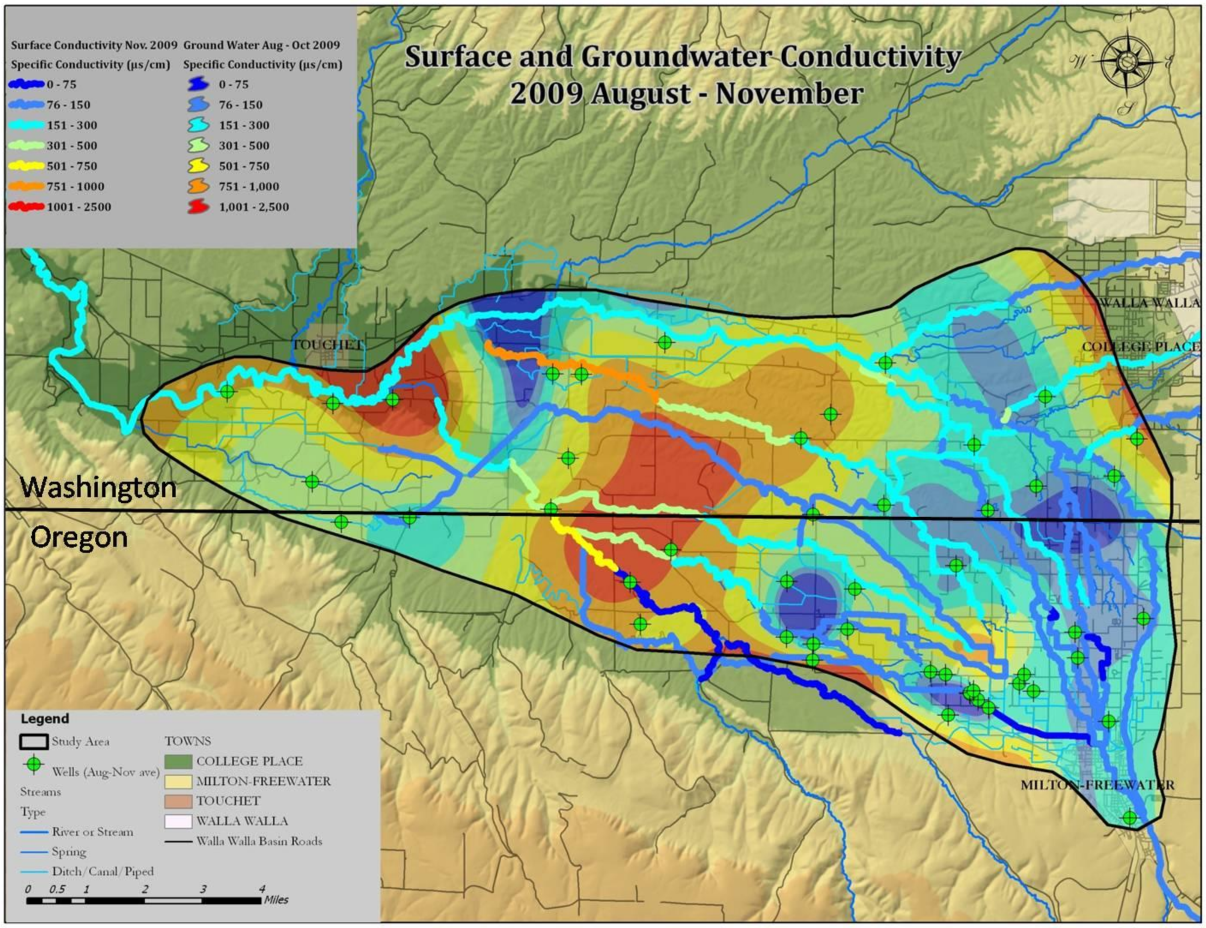


**Figure 47. Groundwater Specific Conductance Map (Baker T., 2010)**

## Spring-Creek Responses

Since one of the stated purposes of the aquifer recharge is to stabilize and restore historic spring flows, an important part of documenting the system wide responses is to link groundwater changes interpreted to be caused by recharge operations, to the springs that flow from this aquifer system. OSU's IWFM modeling work in 2008 provided us some the first supporting evidence linking both HBDIC operations and the operation of unlined canals to the recharge of the shallow aquifer system. **Figure** 48 depicts the three scenarios run by the 2008 model for the flow in the Johnson Spring-Creek system which included; 1) Johnson Creek flow without HBDIC recharge site operations, 2) Johnson Creek flow with HBDIC recharge site operations and 3) Johnson Creek flow with the lining of the canals and without HBDIC recharge site operations (Petrides, 2008). The HBDIC recharge site clearly played a role in why Johnson Creek was running again after 25 years of being dry (**Figure** 48). However other factors helping to restore a partial amount of flow from Johnson Springs were at work preceding the 2004 HBDIC recharge operations. Possibly, with the emerging awareness of the irrigation community that ditches played a positive role in groundwater supply encouraged them to increase the amount and duration of seasonal canal usage. Also this IWFM scenario underlines the importance the man-made canals play in recharging the groundwater system-from which the historic springs are dependent on for their flow.

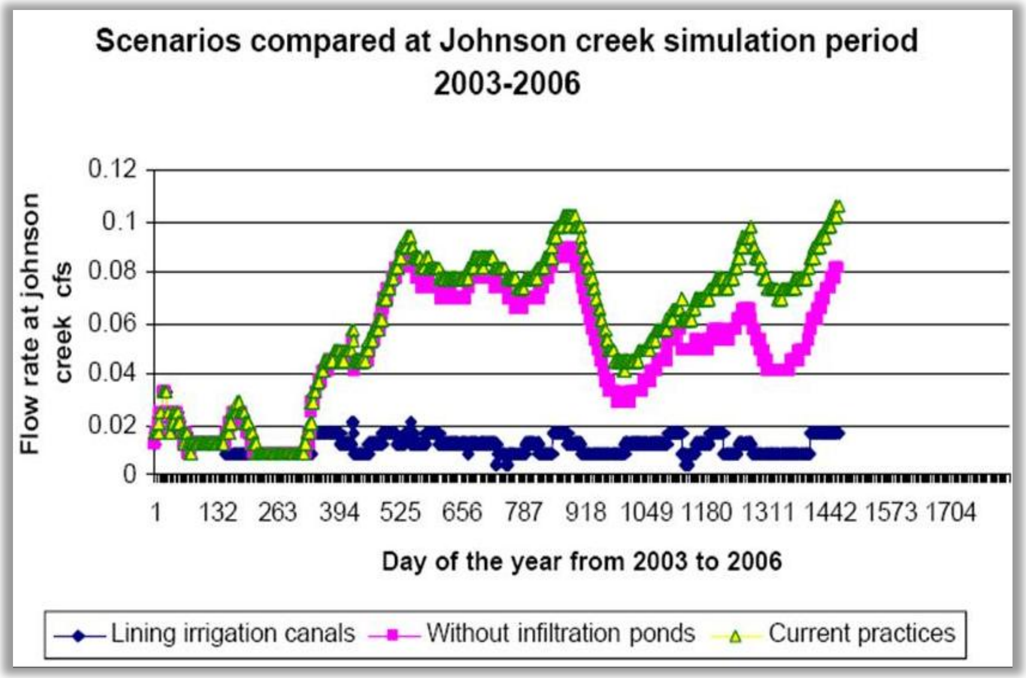


Figure 48. 2008 OSU IWFM Modeling Scenario for Johnson Creek (Petrides, 2008)

Utilizing the transect B2 from the prior groundwater response section, **Figure** 49 illustrates the groundwater and springs monitoring sites from the HBDIC Recharge site to the spring heads of Johnson and Dugger Springs. Plotted next to each of the well sites is the elevation of the ground surface (top of grade) that was surveyed by WWBWC staff during summer 2009 (Patten S. , 2010). Moving down gradient, Transect B2 covers a total distance of about 0.9 miles with a total change in topographic surface of about 70 feet from the HBDIC recharge site (~793 feet) to both flow gauges on Johnson Creek (~723 feet) and Dugger Creek Springs (724 feet). This translates into about a 1.3 % grade of topographic slope.

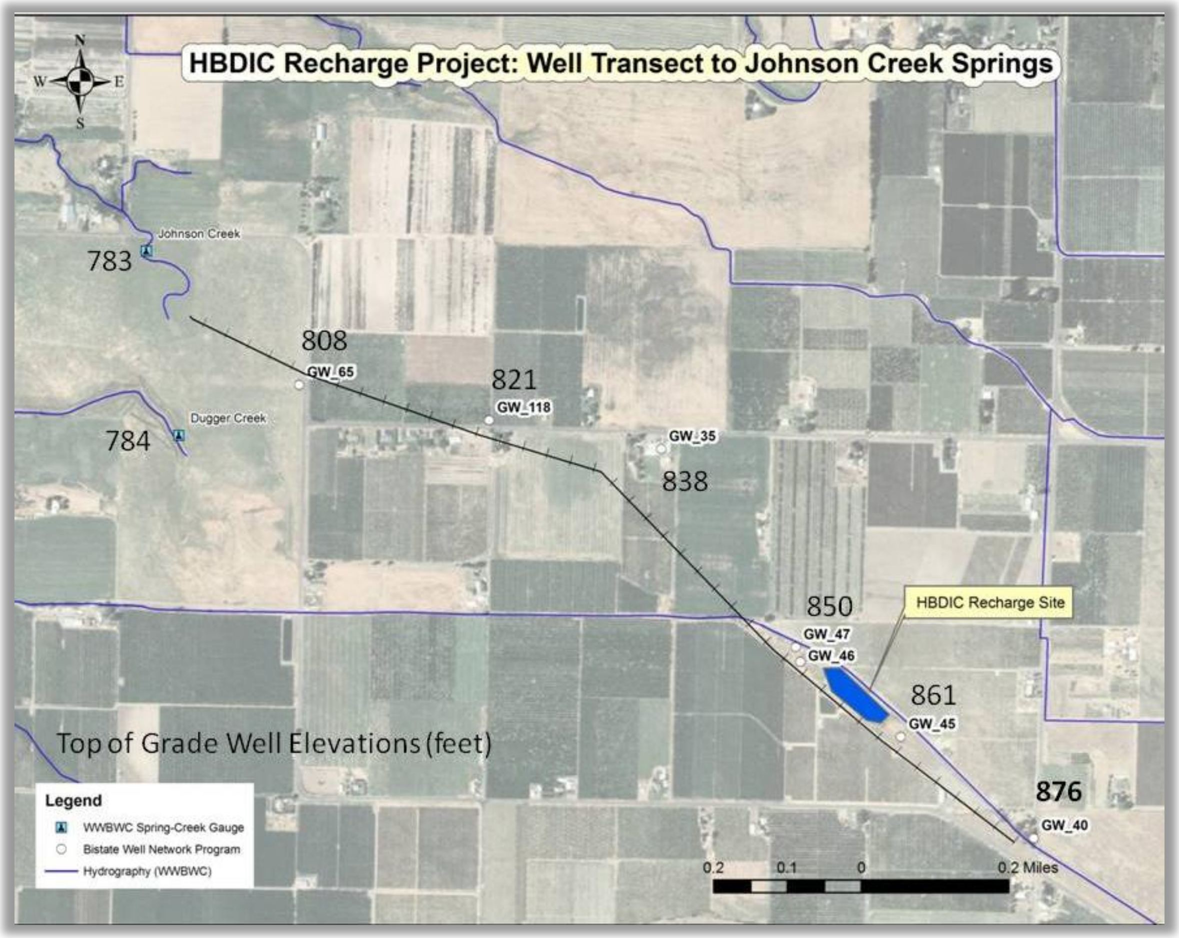


Figure 49. Transect from HBDIC project site headwaters of Johnson and Dugger Creek Springs

**Figure** 50 shows hydrographs for WWBWC monitoring wells from GW-40 to GW-65 along this transect with GW-65 being the closest to the headwaters of both springs. The groundwater infiltration pressure perturbations (denoted here at R-1, R-2, and R-3) can be tracked down gradient through the water table toward the near-spring well site, GW-65. It should be noted that GW-35 is a shallow well that has some use associated with it, which explains the periodic drawdown in it.

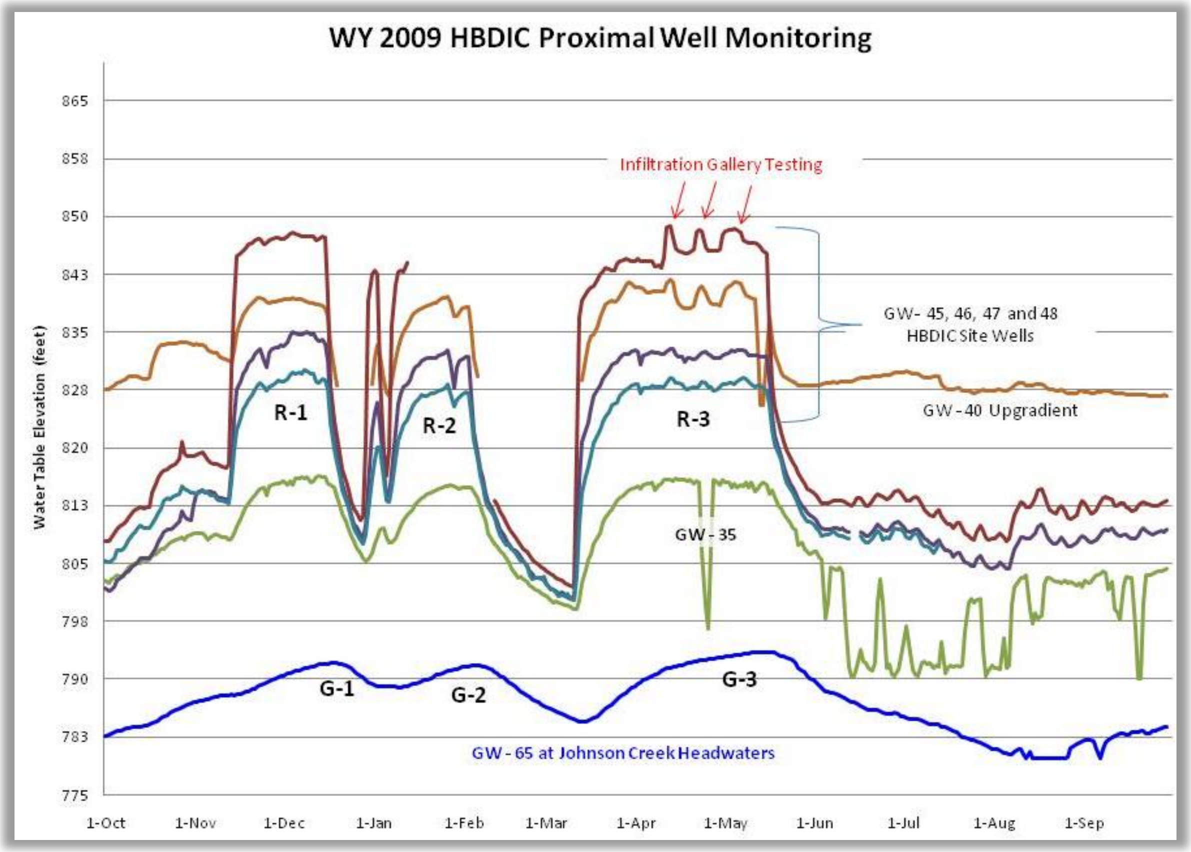


**Figure 50. WWBWC Monitoring Wells (Transect B2) from HBDIC Site to near Headwaters of Johnson Creek Springs**

Utilizing the changes in water level from recharge operations at GW-65 we now can look to the WWBWC spring gauges for signs of groundwater-to-spring-discharge similarities. **Figure** 51 shows this well site relative to the headwaters of both Johnson and Dugger creek springs. The horizontal distances between this well site and the actual spring heads were not surveyed as a part of this project, but were measured using the Arc-GIS distance tool. Johnson Creek's South Fork springs are approximately 1059 feet from GW-65 with a slope of 2.4% (25 feet vertical in 1059 feet horizontal). Dugger Creek spring is approximately 929 feet from GW-65 with a slope of 2.6%. These marked increases in topographic slopes relative to the estimated 1.43% slope from GW-45 to GW-65 (4780 feet) may help explain why these springs emerge at this point in the aquifer system. Other factors likely playing a role in where springs emerge are changes in stratigraphy that may decrease the permeability of the saturated and unsaturated zones. With an increase in groundwater slope and a decrease in permeability (e.g. likely due to cataclysmic Missoula flood deposition of clays and Touchet bed materials) faster moving groundwater would be forced upward (mounding) toward the topographic surface producing the historic springs that the USGS (Piper, 1933) likened to 'spillways on a reservoir'.

The WWBWC surface-groundwater monitoring network also includes more than 50 small-order springs, creeks and ditch sites throughout the Walla Walla River Valley (Lewis, 2009). The WWBWC has three relevant gauge sites to monitor spring and creek flow in these two subbasins. WWBWC gauge # LWSJ (South Fork Johnson Creek spring) measures the elevation of a pond fed exclusively by South Fork Johnson Springs (**Figure** 52). This site along with the other gauge sites were surveyed (Patten S. , 2010) with the purpose of tracking these recharge-to-spring physical connections. WWBWC gauge #LWDC1 measures flow (cfs) out of a series of springs at the headwaters of Dugger creek. The WWBWC installed a weir structure at the site and placed a water level logger and staff gauge at the site. Periodic in-stream stage measurements are recorded and used to calculate flow data. While the site does not capture all of the numerous springs along the headwaters of Dugger Creek, it does provide an understanding of the timing and volumes of flow arising from groundwater changes. WWBWC site #LWJG is a continuous level logger placed in the engineered intake weir for the Johnson Creek reconnection pipeline (Bower R. , 2008). It was installed in 2007 with the first two full years of data being 2008 and 2009. It should be noted however that this site is downstream from the springs and there are a number of active surface water rights that may influence the data recorded at this site. The map also shows other unmapped spring-seeps that likely provide some flow to Johnson and Dugger creeks. These features can be seen as wetland type swales in the fields near GW-65.

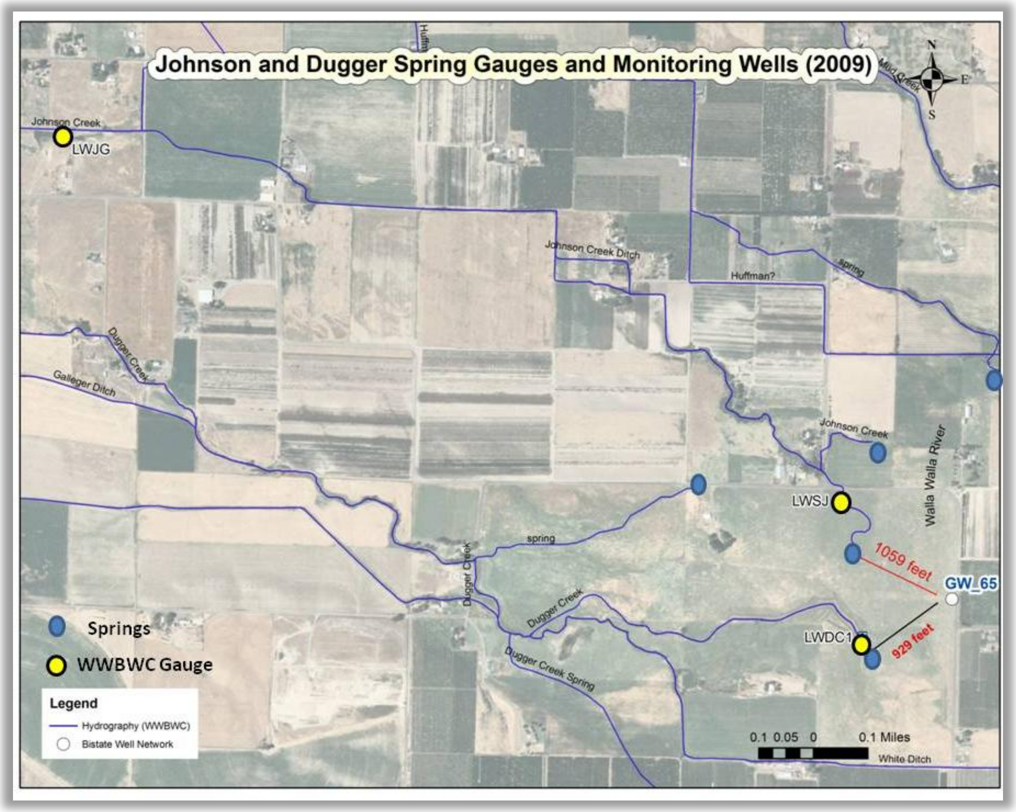


Figure 51. Aerial Map of GW-65 and Gauges-Springs on Johnson and Dugger Creeks

Figure 52. South Fork Johnson Springs (Pond) – Before and After HBDIC Operations (Bower)

Utilizing the water level elevation data from WY 2009 (October 1st 2008 through September 30th 2009) for both GW-65 and the spring-pond level data from LWSJ a graphical comparison was done (**Figure** 53). Groundwater level peaks G-1, G-2 and G-3 appear to correspond directly to pond water levels peaks Sp-1, Sp-2 and Sp-3 in the spring-fed pond. Therefore with this data set we can demonstrate the following logic:

Recharge Action = Groundwater Response = Spring Response

R-1 = G-1 = SP-1

R-2 = G-2 = SP-2

R-3 = G-2 = SP-3

Therefore:

Recharge Action = Spring Response

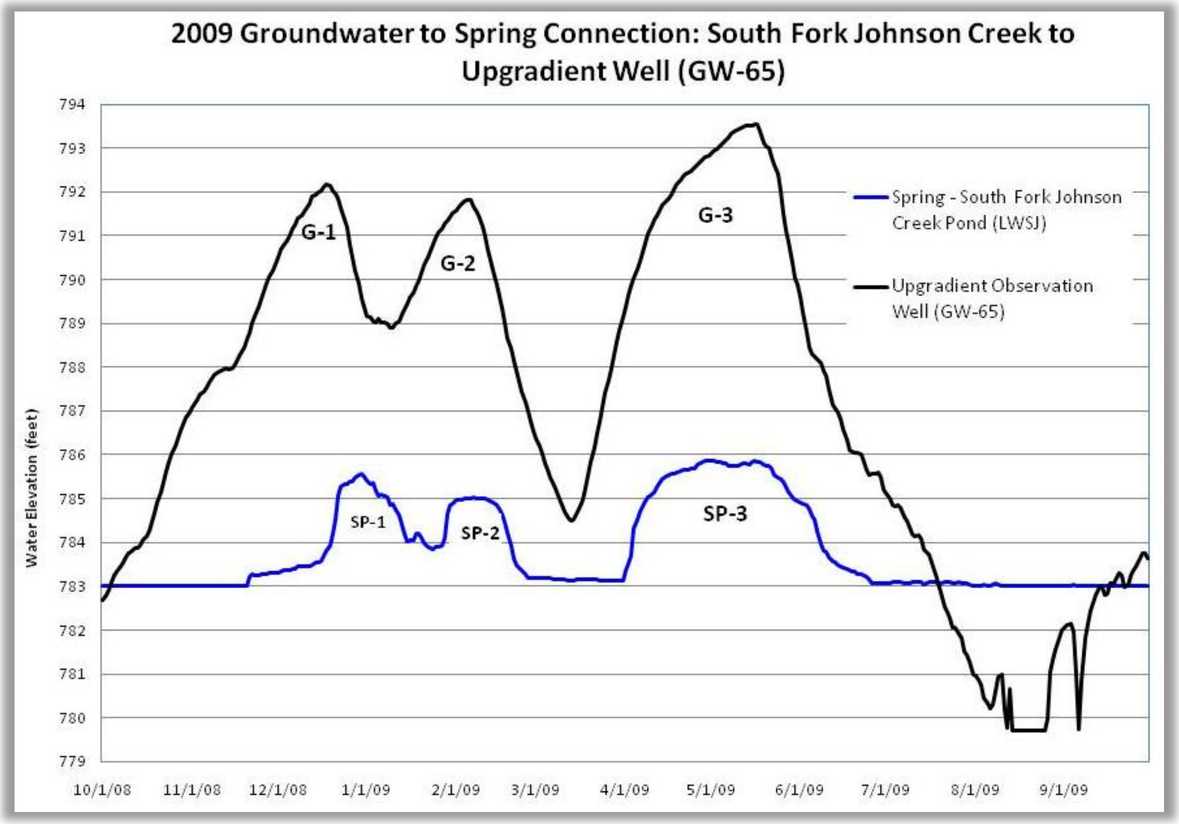


**Figure 53. GW-65 vs LWJS Comparison of Groundwater to Spring Response to HBDIC Recharge Project Operations**

Starting in the early 1930s some historic data was collected by the USGS (Piper, 1933) in support of the Supreme Court case Oregon v. Washington over management of the Bi-state Walla Walla and Little Walla Walla River system. The State of Oregon continued collecting both surface and groundwater data on many of the springs until the middle 1940s, and contined some of the well monitoring sites until present. Using historic data collected from 1932 through 1942 and WWBWC gauge data for Johnson Creek we made a comparision of historic versus current flow conditions. Historic grab sample data was compared against daily-average data that the WWBWC has collected. In order to graph them together, WWBWC data was averaged to monthly values that could be compared with the cooresponding values of the historic dataset. **Figure** 54 shows this comparison for historic water years 1932-34, 36-43 against current data from water years 2008 and 2009. For the water years 2008 and 2009 we utilized the WWBWC gauge data from LWJG as well as a gauge measuring the tail-water from the HBDIC Richartz Pipeline. The tail water was subtracted from the Johnson Creek flow as it is there artifically and would not represent a true comparison to historic conditions.

Historical data shows a relatively constant flow throughout the year which corresponds to more total groundwater storage available to provide this baseflow. The current data mimics the general pattern of the historic flows where a smaller peak flow value in the fall (November-December) and a large peak flow during the spring freshet (April-June). WY 2008 appears to be lower than the subsequent

WY 2009 flows for Johnson Creek. The early season WY 2009 data was not available due to a faulty logger. Clearly the groundwater to spring pattern for this location helped to better understand that groundwater recharge and discharge up gradient lead to flows in the down gradient Johnson Creek springs.

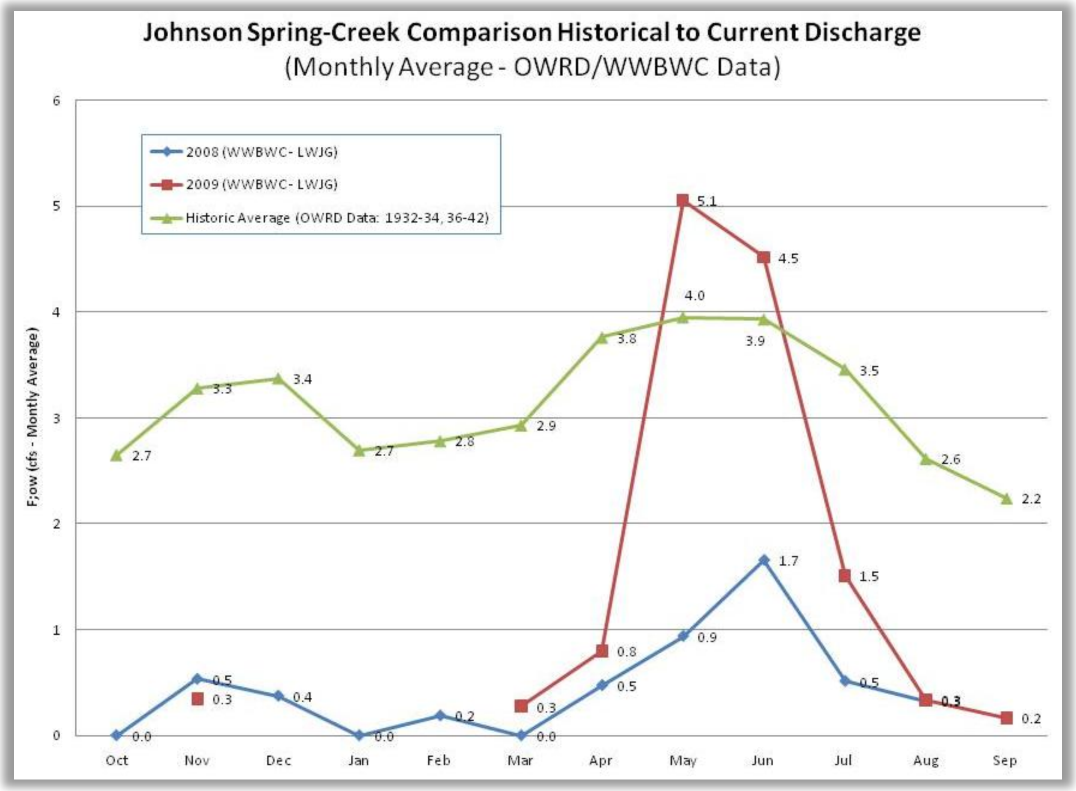


Figure 54. Comparison of Historic versus Current Johnson Spring-Creek flows (OWRD/USGS and WWBWC).

Turning to the other proximal springs relative to the GW-65, Dugger Creek Springs; **Figure** 55 shows the 2008 water year flow data for the spring gauge at Dugger Creek Springs relative to the groundwater pertubations from HBDIC recharge activities (GW-65). Similar to that shown in the Johnson Creek datasets, Dugger Creek surface flows also seem to correspond directly to HBDIC recharge site operations.

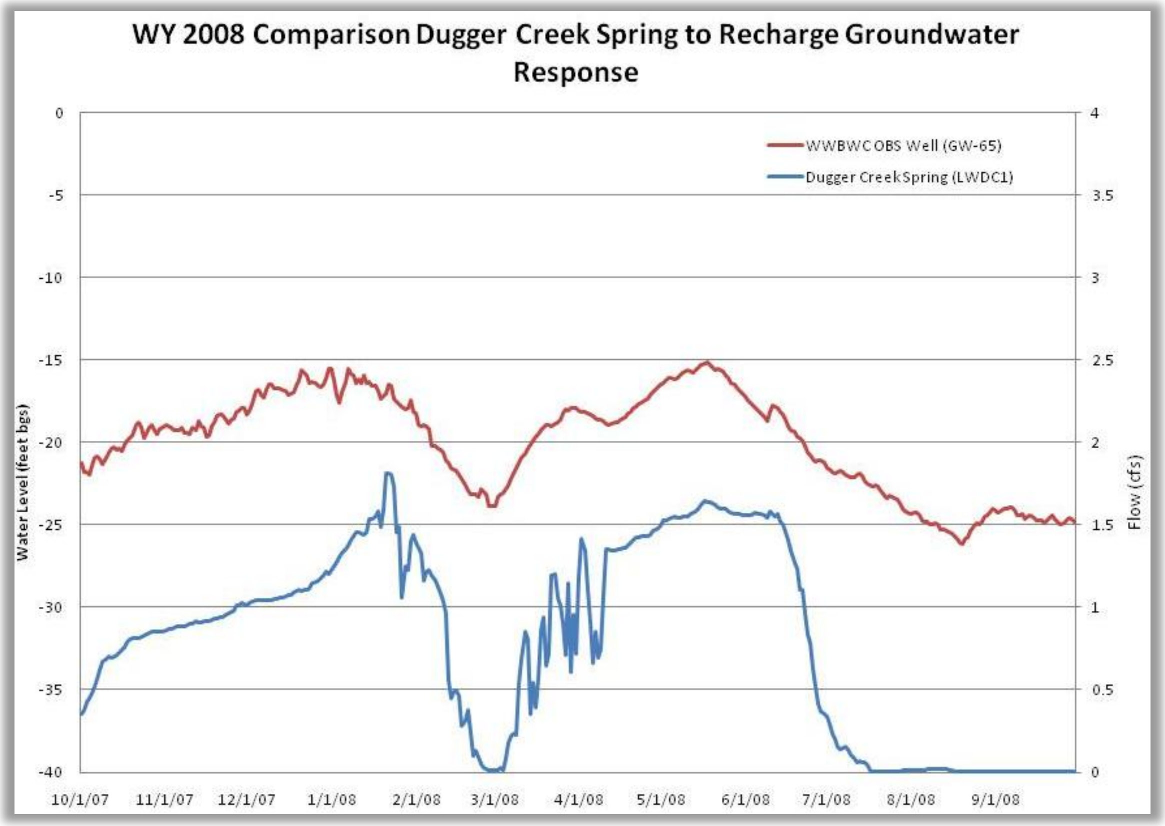


**Figure 55. Comparison of Recharge Groundwater Response to Dugger creek Flow (WY 2008)**

## Linking Spring Responses to Declines in Groundwater Storage

The seasonal fluctuations of the water table in the sub-catchments discussed in the previous sections can be shown to link both the infiltration of water from recharge to the discharge of water through groundwater extraction. However with a system appearing this responsive to change, how is groundwater storage as described in the previous sections actually expressed?

In an early section, **Figure**s 8 and 9 showed that the historic static water table readings showed high variably in levels for any given water year. This variability can be further defined by plotting the values by month to show seasonal change. **Figure 56** shows a summary of water table measurements taken at the OWRD State Observation Well #850 from the 1930's until present. Years with the most monthly static water measurements were selected and synthetic data was generated to map the seasonal trend apparent in the entire dataset. Starting in the 1930s through early 2000 the seasonal pattern of the water table are reasonably consistent across the period of record. However, while the pattern is similar the height of a given year (Y-axis) decreases through time toward the bottom of the well, which subsequently went dry. This overall drop in average readings represents the historical loss of storage in the aquifer system. As spring flow has been shown to be linked to elevation of the groundwater this explains why springs such as Dugger or Johnson Creeks flowed perennially in the past but now flow only when the elevation of the peaks (**Figure** 56) are above the required elevation at the surface. This helps us better understand the role storage plays in the base flows of springs and likely the Walla Walla River.

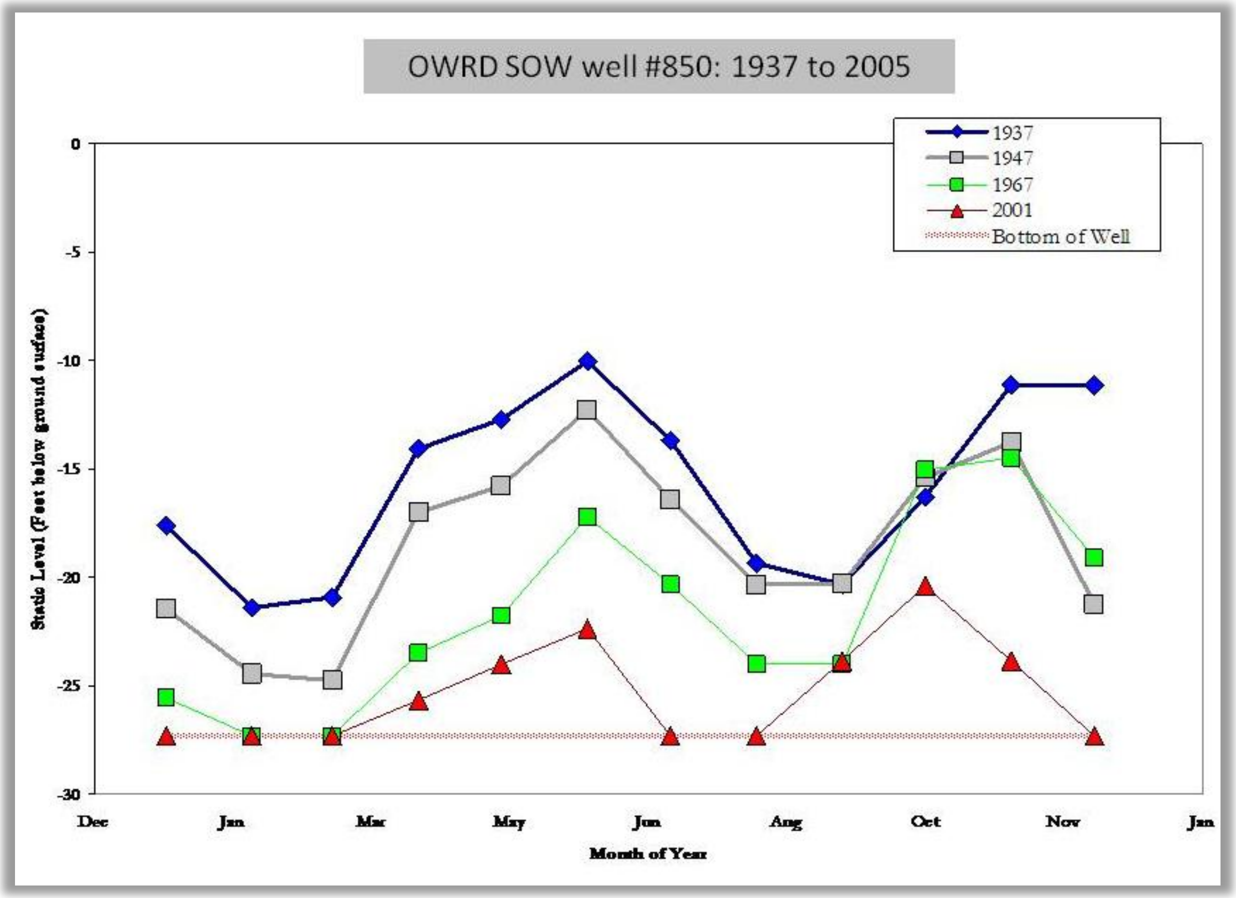


Figure 56. Walla Walla Basin Aquifer Water Table Fluctuations and Historical Trends

## Other Recharge Results: Johnson Creek Recovery

In the early 1930s, just one of the three springs that feed Johnson Creek was measured to range between 2-4 cfs during the summer months. During that time, Johnson Creek served a series of water rights through and past the town of Umapine and most likely was the primary water supply during the establishment of the town in the mid-1800s. For decades what little water came out of the springs, didn't make it down to the lower end of the system.

Starting in 2003, the flows are returning to Johnson Creek after being dry for nearly three decades and appeared to incrementally increase from the subsequent year. The headwaters of Johnson Creek, like the observation well SOW #853 discussed earlier, are directly down gradient from both the Hudson Bay District Improvement Company Aquifer Recharge project and the other up gradient water management changes mentioned earlier. During the winter of 2007, the WWBWC, HBDIC and citizens from the town of Umapine, using OWEB funding, worked together to reconnect this disconnected tributary to the Walla Walla River via the Dugger-Schwartz-Pine Creek tributary system. Today Johnson Creek flows for a portion of the water year directly to Dugger Creek (**Figure** 57). This is water that had not been historically available for down gradient flow restoration before the HBDIC testing site operations. These results emphasize both the ability of recharge to play a role in helping to restore flow to historic springs and serve as a cautionary note on recharge and down gradient springs that have been abandoned due to declining flows.

**Figure 57. Johnson Creek flowing again after 25 years (Umapine, Oregon – Bower)**

## Summary of Spreading Basins Testing and Recommendations

Spreading basins are effective at HBDIC and have shown their ability to move large amounts of water into the groundwater system. Relative to the value of the water being stored, this tool can be considered the preferred method of water storage. Results from the 2004-9 testing indicate that clogging and/or subsurface mounding of groundwater are issues that will need to be addressed for the long term operations of this site. Off-season treatment and removal of the sediment layers that appear to be accumulating is recommended as first steps toward this goal. There are numerous techniques used by larger recharge programs that can help address these issues of long term operations. Water quality for the site, both source and recharged groundwater, has shown itself to be of good and consistent quality. On-site water table monitoring may indicate that localized groundwater storage is recovering from HBDIC recharge activities, although additional years of monitoring will help confirm this trend. Additional site upgrades should include a reexamination of the intake structure and its ability to measure flow more effectively with regards to White Ditch fluctuations as well as water backing up from the first spreading basin. The overflow flume site should also be upgraded from a portable weir to a concrete structure to ensure that excessive water leaving the site is measured.

# PART III. INFILTRATION GALLERIES

## Infiltration Gallery Testing

### Overview

Making irrigation systems more efficient through the lining and piping of irrigation canals is another tool for water management. While you lose the aquifer recharge benefits you gain more surface water volume with which to irrigate. Irrigation efficiency in these terms does provide the Walla Walla basin with a method to better manage surface waters. However with the urgency of addressing the declining aquifer system and drying up of spring-creeks, developing methods of incorporating managed aquifer recharge into piped and lined canals systems is critical. The idea is to save water during times of scarcity without losing the ability to replenish the natural groundwater storage of the system. Furthermore the availability of acres of open ground, such as used for spreading basins is not always available or cost effective. Subsequently numerous smaller recharge areas spread spatially in watershed may be helpful to reduce the subsurface mounding created by larger projects and better disperse the storage of water.

The concept of recharging groundwater in subsurface galleries or chambers is not a new one. For years storm water managers in municipalities and along road systems have devised ways to collect run-off from impervious surfaces and infiltrate that water into the subsurface so as to avoid overland flow and flooding. In these situations the water can often contain pollutants and suspended solids that make their deposal difficult. The risk of toxic water quality issues along with the clogging of disposal area makes this a unique water management challenge. More recently many municipalities in water restricted areas of the world are developing these subsurface recharge galleries to be used in parks, golf courses, and in some cases for capturing run-off from roof tops for backyard recharge programs.

The methods and designs utilized in the infiltrating of storm water can be built upon in the case of recharging with clean winter source water such as the case at the HBDIC recharge site. The HBDIC team decided that there was a need to test the varying methods and materials for infiltrating recharge water into the subsurface. A number of designs and materials were reviewed to determine which infiltration galleries were tested including material costs versus their perceived effectiveness at recharging groundwater. From reviewing other recharge testing projects we knew that the most difficult challenge for these systems was clogging. The presence of suspended solids in the source water along with the possibility of biological clogging from algae growth in the galleries was an issue that has thwarted effectiveness of these projects in the past. In designing the testing galleries, collaboration was established with Adam Hutchinson who leads the Orange County Water District's managed aquifer recharge (MAR) program. The Orange County team has been testing infiltration galleries type MAR projects under golf courses, in city parks and in other locations where small, discreet subsurface recharge sites were needed to maximize the programs ability to recharge and store water. Information from their experiences was used extensively to design the galleries as well as develop the testing methodology for the project.

## Infiltration Gallery Designs, Permitting and Testing

Four types of subsurface materials were used to design for infiltration galleries at the upper end of the HBDIC recharge site (See **Figure** 25). The materials were chosen primarily to compare the cost of materials relative to their anticipated effective recharge rates and how those rates may decrease through time due to clogging. Infiltration gallery # 1 (IG-1) was constructed using 4" perforated pipe (ADS) that can be purchased inexpensively from any home builder supply and its easy installation allowed for low labor costs. Infiltration Gallery #2 (IG-2) utilized 4 inch perforated PVC pipe typically used in domestic septic-tiling systems. This was also fairly easy to install; also keeping the overall constructions costs down. Galleries #3 and #4 both utilized materials developed by companies designing subsurface infiltration methods for the storm water industry. Infiltration Gallery #3 (IG-3) was built with *Stormtech Chambers* that are open bottomed allowing the water to infiltrate downward. Further, they can be designed to be periodically cleaned of sediment and debris. Infiltration gallery #4 (IG-4) utilized *Atlantis Raintanks* which resemble boxes that are open on all sides allowing for intra-chamber water exchange, but the 336 “tanks” each require assembly making their installation costs the highest of the four designs**.** Preliminary trials of these ‘tank’ style galleries were conducted successfully in the City of Adelaide Australia (Higginson, 2007 )**.**

**Figure** 58 shows the general schematic of the completed IG testing area while engineered designs for the galleries, turnout and other structures can be found at the WWBWC offices. Water is diverted from the White Ditch via a self-cleaning, screened weir (A) situated on the bottom of the canal. Water moves down gradient through the 21 inch main pipe to a stilling well which has the primary control valve (butterfly) to release water in to the testing galleries (B). An *YSI* Model # 6920 V2 turbidity-temperature-conductivity meter is at this location allowing continuous data recording during the operation of the galleries. IG-1, 2, 3, and 4 are supplied water from the main pipeline via 5” connector pipes (C) that have 5 inch butterfly control valves and *McCrometer* (Model #EO3000) propeller-style flow meters that measure both instantaneous flow rates (gallons per minute) as well as totalize the inflow (total gallons x 100). Each set of galleries were installed with air-release vents that also provide a method by which to visually inspect inside the gallery. These vents are located in different locations depending on the type of gallery. At the end of the main line is an overflow basin (D) that allows a location to drain any accumulated sediment from the intake and main pipeline structure prior to turning on the infiltration galleries. Adjacent to the gallery testing area HBDIC Observation Well #4 (GW-45) is located just downgradient (E). **Figures** 59 and 60 show the materials and installation of the IG-3 and IG-4 galleries.

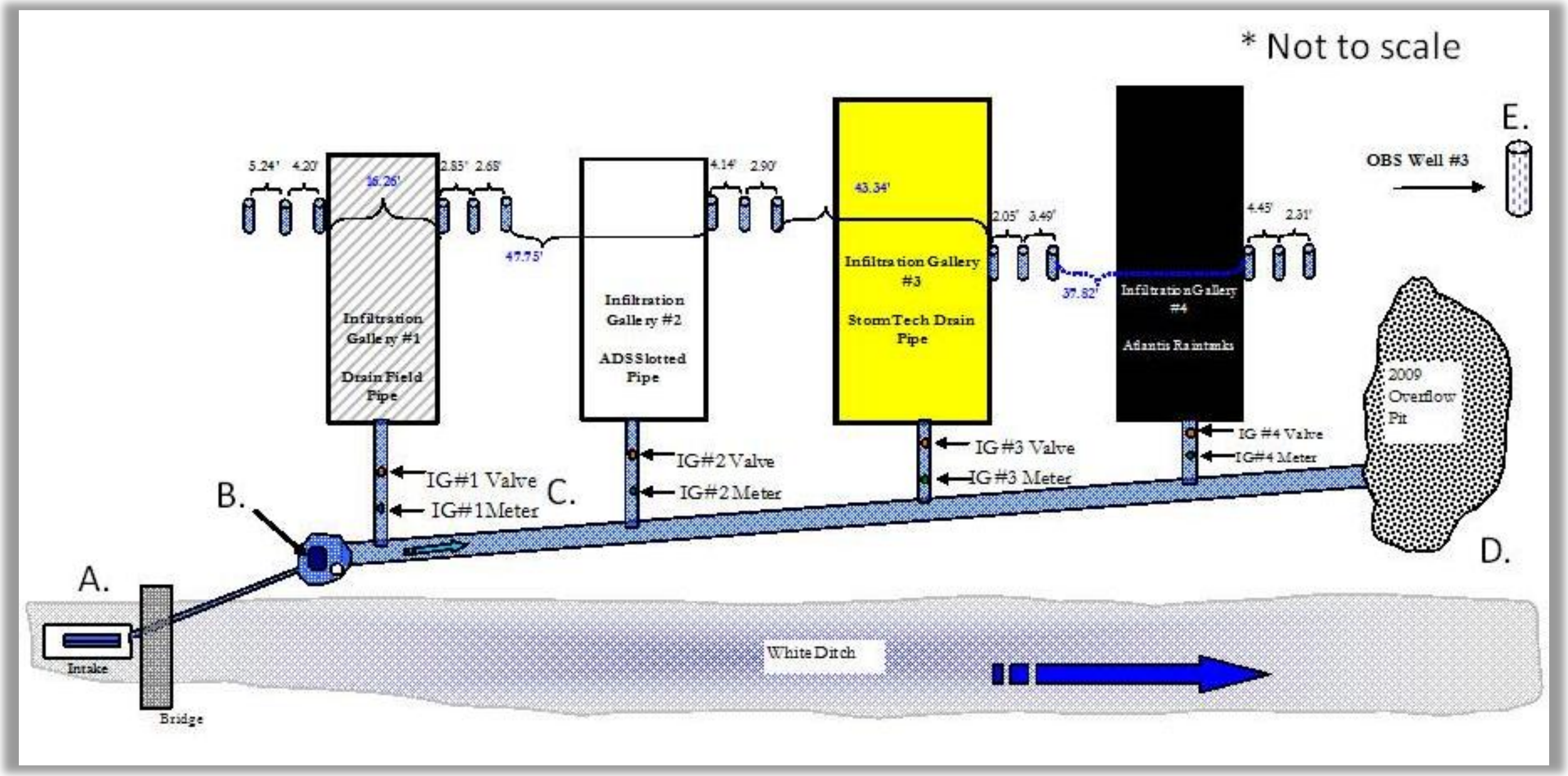
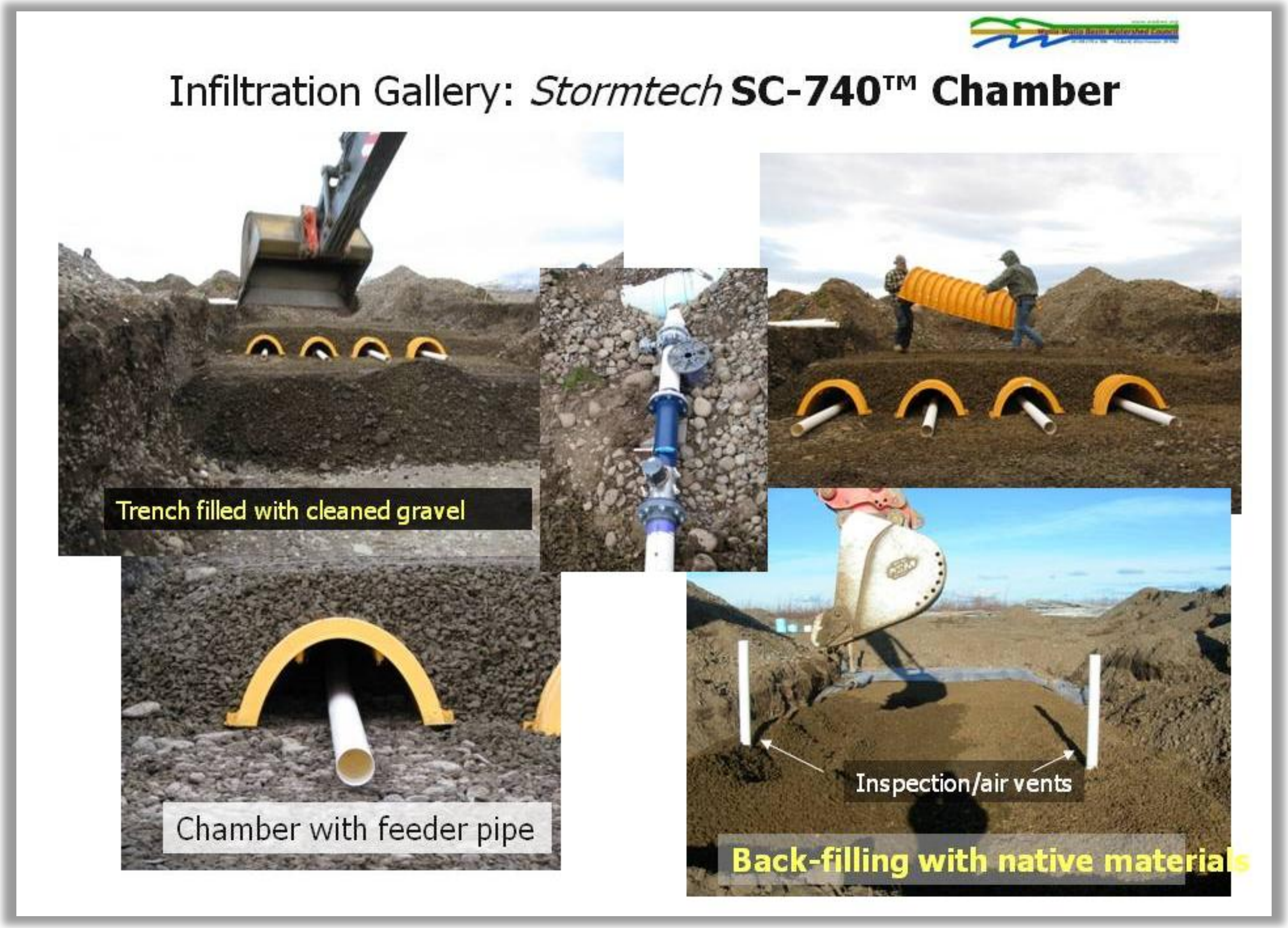


Figure 58 Infiltration Gallery Testing Area (HBDIC Site)



Infiltration Gallery: *Stormtech* **SC-740™ Chamber**

Figure 59. Infiltration Gallery #3 - Stormtech Chamber Installation (2008)

Infiltration Galleries: *Atlantis® D-Raintank® Tank Module*

Raintanks being deployed

Gallery top: filter fabric and mesh

HBDIC Testing Site: 1000 $feet^2$ infiltration area

Intake: Value and metered

Figure 60. Infiltration Gallery #4 - Atlantis Raintanks Installation (2008)

Next to each of the galleries piezometers were installed in perpendicular transects away from the galleries in order to measure both groundwater mounding as well as water quality (PZ-1 through PZ-15). The piezometers varied on depth from approximately 4 to 11 feet in length with a horizontal spacing of 2 to 5 feet between each gallery with the first piezometer located directly adjacent to the infiltration gallery. Water level recorders (*In-situ Inc. LT100, Unvented, pressured transducers)* were used to measure water levels and temperatures during each of the individualized gallery testing. Each piezometer was outfitted with pre-packed mesh screens so that samples could be extracted effectively from each measurement point**. Figure** 61 shows the various gallery-specific monitoring equipment installed at the site.

Water recharged below the ground surface is classified by the State of Oregon and the Federal Environmental Protection Agency as requiring special permitting and review under the Underground Injection Control (UIC) permitting program. The HBDIC team worked with the Department of Environmental Quality (ODEQ) to apply for and receive a UIC permit to test all four galleries (2009, ODEQ's UIC # 13233-1, 13233-2, 13233-3, 13233-4). Under this approved application (Bower R. , WWBWC-HBDIC's Infiltration Gallery Testing Project: Application for UIC Permit (ODEQ), 2008) a summary of results for the HBDIC site water quality monitoring program and the results to-date were supplemented with detailed gallery designs and additional turbidity, total suspended solids (TSS) and total organic carbon (TOC) testing to track potential clogging of the galleries. As the HBDIC recharge site already has a permit from Oregon Water Resource Department (OWRD #LL1189) to divert water for testing, no further water use permits were required. The galleries were specifically designed to have a separate water intake from that of the site's spreading basins so they could be tested independently. While the water recharged would be important to helping the overall goal of recharging the aquifer, the main purpose of this installation was for testing purposes. After receiving the permit in December 2008, they were constructed over an 8 week period and were ready for testing starting in late January 2009.

### Infiltration Gallery Testing Plan

The scheduled testing for the first recharge session aimed to accomplish two main goals. First, each gallery would be initially run independently of the others to measure the individual recharge rates and monitor any immediate changes relative to clogging during the first week of operations. Each gallery was to be run for a week and then turned off for 24 hours before the next down gradient gallery was turned on. Operating more than one gallery at once also created the potential problem of cross influencing each other through the mounding of subsurface water due the close proximity of the galleries therefore, individualized testing was preferred. The testing would take a total of 5 weeks to complete. After this initial individualized testing the galleries were to be all operated in tandem for the remaining portion of 2009 to track any long-term changes in recharge rates over a recharge season or from year to year.

Infiltration Gallery Instrumentation

Cable: Insitu LT100 Pressure Transducer

Atlantis Raintanks

Prepacked Screen: water quality

Intake Flow meter

Intake pipe with value and flow meter

Piezometer: water levels and quality

Figure 61. Infiltration Gallery monitoring equipment (2009)

Turbidity, TSS and TOC measurements were to be taken during both the individualized and tandem testing at several pertinent locations and sent to *Edge Analytical Inc.* in Burlingame, Washington. Samples were collected in sterile, 250 ml bottles from the channels edge at the Little Walla Walla River diversion from the source waters of the Walla Walla River. Measurements were also taken at the intake structure of the galleries where the YSI continuous meter was recording turbidity and total dissolved solids in 15-minute intervals during operations. These samples could then be compared to build a regression relationship between TSS and turbidity. By characterizing this relationship the use of turbidity meter can help both with the testing of the galleries as well as establishing water quality guidelines by which to operate the HBDIC and other future MAR sites in the basin. When this information is further linked to mainstem flow, real-time monitoring could help to automate a basin wide recharge system. The purpose of measuring at both the Walla Walla River and at the HBDIC site was to further investigate and potential change in TSS and TOC values as the water moved through the conveyance system.

## Infiltration Gallery Testing Results – Preliminary

Construction of the site lasted until late January 2009, just a few days before the Little Walla Walla diversion annual shut down. This allowed only a short test of IG-1 to start the season. Later in February all the galleries were operated for 5-7 days to test all of their individual recharge rates and map the mounding with the piezometers. It was found during the operations of IG-2, the meter's totalizer was not operating. This made the instantaneous portion of the meter the only way by which to monitoring operations. At IG-3 and IG-4 it was found that the 5" feeder pipe was sized too small for these two galleries as air vents at the far end of the galleries showed water was not making to the gallery ends. Therefore, the results for these two galleries under-estimate the true operation rates for *Stormtech* and *Atlantis* style designs. After the individual gallery testing was completed, galleries were operated as spaced pairs (IG-1 and IG-3, IG-2 and IG-4). Lastly, the YSI turbidity meter had power-source difficulties that limited the 2008-9 water quality monitoring to TSS lab sample source to intake comparisons.

At the time of this report the 2010 season has not been completed, so the 2008-9 results are shown along with preliminary information for 2009-10 season (**Table** 6). The galleries have different infiltration areas (due to the materials used and restriction on the site area) and once the rates were normalized by infiltration-area IG-2 seems to have the highest average infiltration rate (2008-9) of 1.67 cfs. Of course with IG-3 and IG-4 having a restricted inflow pipe, their values are likely to be significantly higher than shown here. The galleries combined to recharge approximately 180 acre-feet of additional recharge water (2008-9) during a very limited operation period. Preliminary 2009-10 results show some potential changes in flow rates with all galleries appearing to lose 10-20 gpm from the prior season. IG-1 appears to be operating at about 1/3 of the prior season but it is unclear if that is a factor of clogging or some influence of individual versus dual (IG-1 and IG-3) gallery operations. The galleries have contributed approximately 488 acre-feet of additional recharge at the HBDIC site to date.

Reviewing the preliminary TSS samples from the Little Walla Walla Diversion and the IG gallery intake, it appears there may be a weak correlation between sites suggesting some attenuation of suspended solids between locations (**Figure** 62). Water level data at all 15 piezometers provided detailed water mounding profiles for each of the galleries during the 2008-9 seasons as shown for IG-1 in **Figure** 63.

| Recharge Season | Infiltration Gallery # | Average Flow (gpm) | Average Flow (cfs) | Infiltration Area ($feet^2$) | Average Flow (cfs) - Area adjusted (1086 feet) | Total Volume (2009) (gallons) | Total Volume (2009) (acre-feet) | **Comments** |
|---|---|---|---|---|---|---|---|---|
| 2008-9 | IG - 1 | 371.3 | 0.83 | 667 | 1.35 | 9,160,000 | 28.1 | Piezometers with TSS sampling |
| 2008-9 | IG - 2 | 460.0 | 1.02 | 667 | 1.67 | *10,156,800* | 31.2 | *Estimated Volume (days x average rate)* |
| 2008-9 | IG - 3 | 539.4 | 1.20 | **1,086** | 1.20 | 15,882,700 | 48.7 | 5" intake constricts total rate |
| 2008-9 | IG - 4 | 568.2 | 1.27 | 1,008 | 1.36 | 23,379,400 | 71.8 | 5" intake constricts total rate |
| **Season Total Recharge Volume** | | | | | | 58,578,900 | **179.8** | IG-2 and Overflow pit not included |
| Recharge Season | Infiltration Gallery # | Flow (gpm) | Average Flow (cfs) | Infiltration Area ($feet^2$) | Average Flow (cfs) - Area adjusted | Total Volume (2009-10) (gallons) | Volume To Date (acre-feet) | **Comments** |
| 2009-10 | IG - 1 | ***115.0*** | 0.26 | 667 | 0.4 | 22,425,200 | 69 | Reduced Rate - clogging or dual operations? |
| 2009-10 | IG - 2 | 452.0 | 1.01 | 667 | 1.6 | N/A | N/A | Volume not estimated |
| 2009-10 | IG - 3 | 520.0 | 1.16 | 1,086 | **1.2** | 22,428,500 | 68.8 | 5" intake constricts total rate |
| 2009-10 | IG - 4 | 560.0 | 1.25 | 1,008 | 1.3 | 30,495,400 | 93.6 | 5" intake constricts total rate |
| 2009-10 | Overflow Basin | 190.0 | 0.42 | N/A | N/A | 25,131,000 | 77.1 | Area changed between seasons |
| **Total Recharge Volume - To Date** | | | | | | 159,059,000 | **488.2** | IG-2 not included |

**Table 6** Infiltration Gallery Testing Preliminary Results

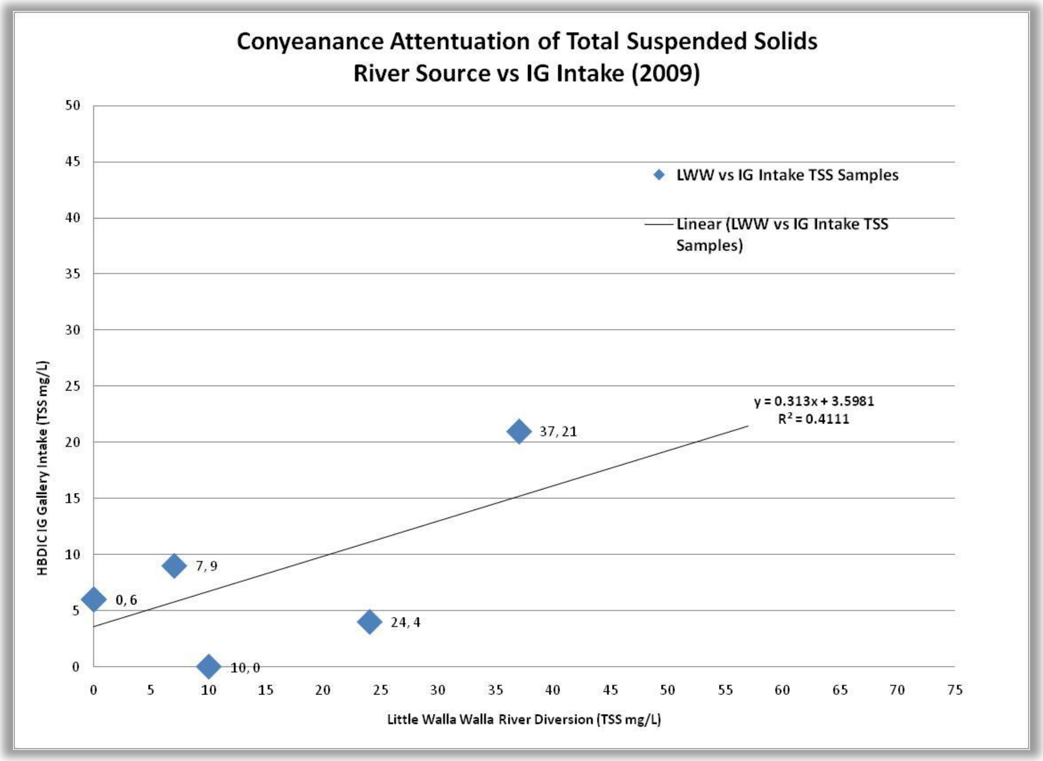


**Figure 62. Preliminary Results of TSS and Conveyance Attenuation from Source to HBDIC Recharge Site**

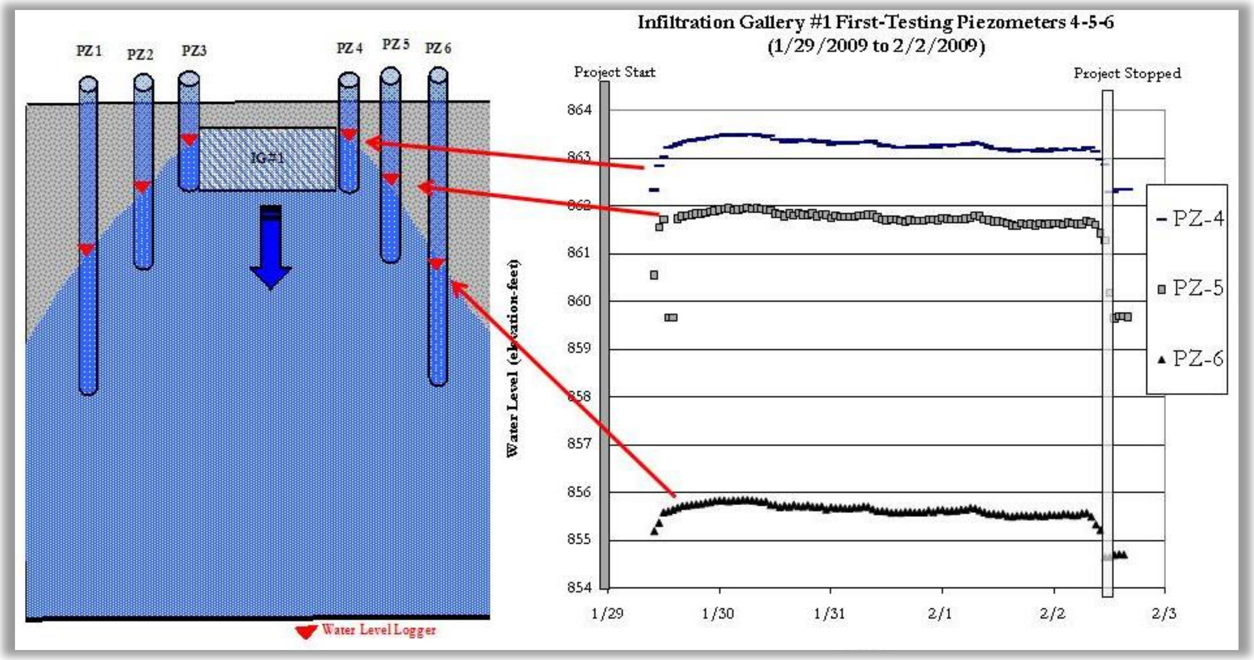


**Figure 63. Piezometer water level results from initial operations of IG-1 gallery (2009)**

## Cost-Effectiveness Summary

The limitations poised by the small intake feeder pipes combined with the galleries being limited in mounding area make doing a straight forward cost-benefit (recharge rate vs. costs) analysis impractical. If the galleries are operated and tested individually in the future, and larger feed pipes are installed in IG-3 and 4, perhaps an estimate can be generated. The galleries as currently configured will serve to test the clogging issue, which is really the most pressing of the original research questions. Table 7 provides a basic break-down of the overall costs of materials for the IG testing as well as a $/foot value for each gallery. Labor should be considered in the construction of these galleries, particularly if numerous galleries were installed around a watershed. It is estimated that labor costs were significantly higher for the IG-3 and IG-4 with the *Raintanks* taking approximately 60 man-hours. Exact labor and materials costs will differ by region and supplier; an extensive analysis was not undertaken for this report.

| Infiltration Galleries Materials | Total Material Costs (2008) | Cost/infiltration Area ($/foot) |
|---|---|---|
| Inlet Structure | $4,300 | n/A |
| Mainline Pipe | $14,200 | n/A |
| Main Value Structure | $3,330 | n/A |
| IG #1 Perforated Pipe | $2,211 | $3.32 |
| IG #2 Drain Tile (septic) | $2,274 | $3.41 |
| IG #3 Stormtech Chambers | $7,764 | $7.15 |
| IG#4 Atlantis Rain Tanks | $10,078 | $10.00 |
| Total | $44,157 | |

**Table 7 General costs breakdown for Infiltration Galleries (does not include gravel).**

## Summary of Infiltration Gallery Testing and Recommendations

Infiltration gallery testing includes not only the physical monitoring and water quality monitoring of various gallery designs but also the process by which they are permitted for operations. The HBDIC recharge team was successful in obtaining UIC permits for the testing site which coupled with the OWRD limited testing license allowed the system to be built for testing. Initial results on recharge rates show that these galleries have the potential to recharge considerable amounts of water if spaced sufficiently from other areas where surface water is infiltrating (e.g. ditches, ponds or natural water bodies). Issues with pipe sizing, meter failures and site placement limited the independent testing results of the galleries. However even with these issues all the galleries will provide long-term clogging information to the HBDIC team over the life of the testing project. Recharge notes do not appear to have varied greatly between the various materials; however the limitations mentioned previously make any firm predictions tenuous. When funding is secured, it is recommend that the faulty flow meter (IG-2) and the limiting 5” feeder pipes (IG-3 and 4) are replaced so that actual flow rates and volumes can be accurately recorded over the next 5 years of the limited testing license. Establishing the TSS to Turbidity Meter rating curve and keeping careful records of operation times, rates and volumes is critical to better assess the most critical issue, clogging.

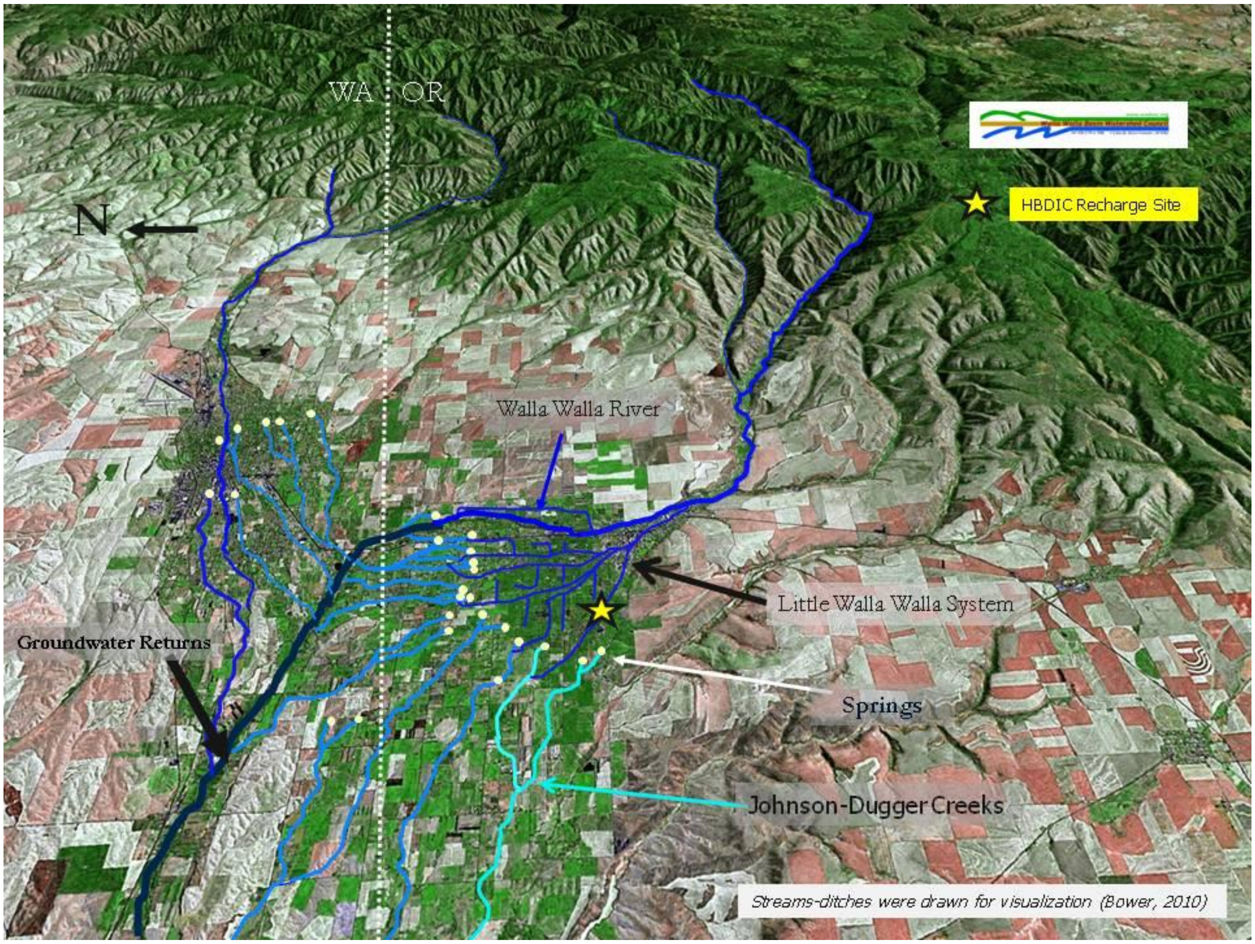
# PART IV. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## Summary of Results

The HBDIC recharge site has been operated for six recharge seasons totaling 602 days of operations. On-site recharge spreading basins and infiltration galleries have recharged the aquifer with more than 13,500 acre-feet of water, which represents more than 21 square-miles a foot deep of water. The OWRD limited testing license that the HBDIC Site operates under (LL-1159) requires that ditch conveyance losses be included under the 50 cfs maximum use quantity, taking the projects total recharged volume to 25,000 acre-feet (40 square-miles a foot deep of water.) Onsite recharge rates have varied by year depending on the water year availability and the infiltration area with *effective average* values between 5.7 to 15 cfs. Basin clogging and water table recovery may also be acting to slightly reduce the surface infiltration rates on site.

Water quality monitoring performed at the site has shown an ambient low-level fecal coliform contamination in the surface water and surrounding shallow aquifer system. Surface water to groundwater treatment through recharge activities may indicate that natural attenuation processes are applicable for the HBDIC site operations. General chemistry results showed no significant findings while only two low-level detections were made of any Soluble Organic Compounds (e.g. pesticides, etc) during this testing period. Water quality of both the source water and groundwater appear to be stable and predictable during the recharge season. Recharge did not degrade groundwater quality.

WWBWC monitoring wells have helped track the recharged water as it moved into the groundwater system. Pressure perturbations directly linked to HBDIC recharge activities were used to track the recharge influence on groundwater response and to down-gradient springs. The springs were showing recovery when compared directly to historic flows recorded during the 1930s and 1940s. From these results the WWBWC-HBDIC team believes the HBDIC recharge site has been successfully testing aquifer recharge and is recharging a portion of the shallow aquifer system. The benefits of groundwater recovery while helping to restore historic spring flows also appear to be linked to HBDIC recharge site operations (**Figure** 64). We believe these results provide the basis by which to pursue the Bi-state ARSR program outlined in the following section of this document.



Streams-ditches were drawn for visualization (Bower, 2010)

**Figure 64. Walla Walla River Basin springs and groundwater returns to the Walla Walla River.**

## Managed Aquifer Recharge – Balancing Storage

The results of testing at the HBDIC site indicate that MAR can be a useful water management tool in the Walla Walla basin. When considering numerous historical as well as new stresses that face the storage of water in the shallow aquifer system, MAR should be considered (**Figure** 65). Other options currently being considered include surface water storage behind dams, large pumping exchanges with the Columbia River and/or curtailment of existing water rights, both irrigation and domestic. Some of these other options require hundreds of millions of dollars while others threaten political polarization of the community. None of the options in themselves can guarantee that the balance of water in this highly interconnected surface-groundwater system will be sustainable for fish and people into the future.

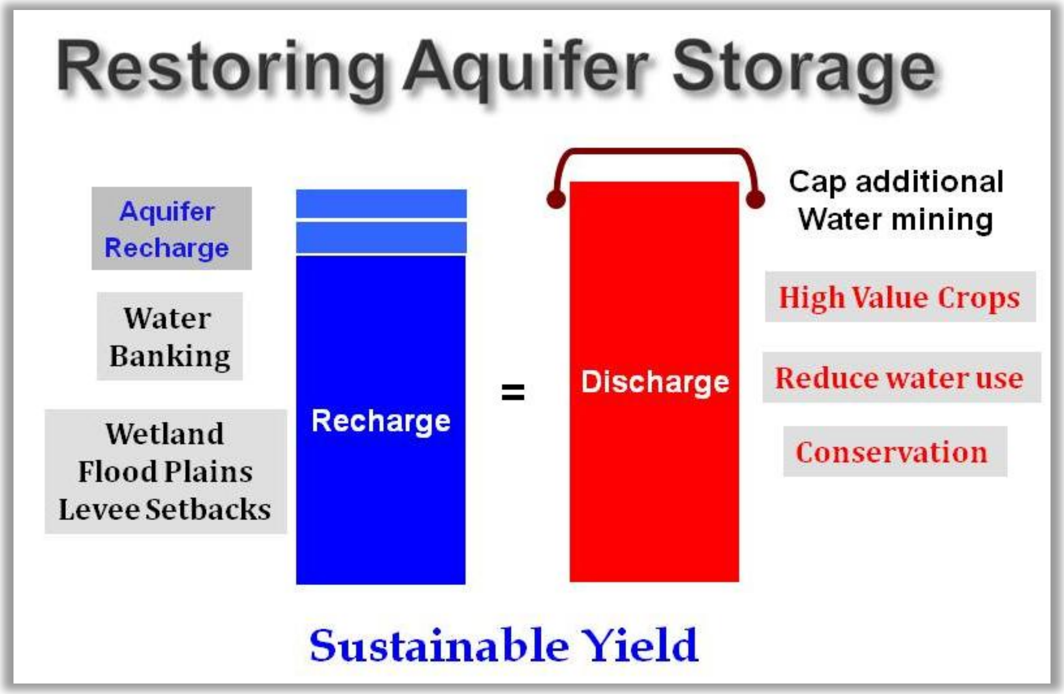


**Figure 65. Balancing Storage with Managed Aquifer Recharge and other methods.**

Managed Aquifer recharge has shown positive results toward being a water management tool for the Walla Walla Basin. As a tool it can be used as it is designed and for nothing more. Other water management strategies that could ensure better management includes restoring wetlands, river and creek flood plains through levee setback projects. Slowing water down after decades of making it move faster through the basin seems the best strategy as these activities also improve the habitat of wildlife and increase the quality of life of the residents of the basin. As supplies of water decrease the value of water will increase, making it more useful to buy and sell water (water banking) or utilizing it with crops of higher commercial value. Finally, using less water through conservation is always the least expensive alternative to all of the above mentioned and should be part of the overall Walla Walla basin strategy.

## Moving Forward: From Testing to Programmatic Response

The operations, analysis, and modeling of the HBDIC Recharge testing site coupled with the information collected at the other 2 Walla Walla basin's recharge sites has provided critical answers to the most pressing questions about aquifer recharge for this basin, including;

1. Aquifer recharge has been shown to effectively transfer seasonally available surface water into the shallow aquifer for the purposes of storage
2. Aquifer recharge has been shown to help restore flows in historical springs that are tributaries to steelhead and redband trout creeks
3. Source water used for aquifer recharge should be shown to have good and consistent quality

4. Aquifer properties have been measured showing this system can provide a viable water storage
5. Continued piping coupled with over-allocated well pumping without mitigation will result in continued spring declines and threatens to jeopardize instream flows throughout the system.

The information generated by this monitoring along with applied research conducted by the WWBWC and its partners has led to vast improvements in our understanding of groundwater conditions and characteristics. Complementing our scientific understanding of the hydrology within the Walla Walla basin, the WWBWC and its partners have also been moving forward with policy development for the Aquifer Recharge and Spring Restoration (ARSR) program. Supporting this effort, in 2009 the State of Washington passed legislation creating the Walla Walla Watershed Management Partnership.[20] The Partnership is a public agency operating under RCW 90.92 (2SHB 1580, Chapter 183, Session Laws of 2009) and is charged with piloting local water management in the Walla Walla Basin. Efforts leading up to the formation of the Partnership were made up of community members including landowners, local governments, conservation groups, tribes, state and federal agencies, and many other entities working to develop local solutions to the unique water issues in the Walla Walla Basin. In Washington, the Partnership integrates local water and watershed management with state oversight, providing a primary governance structure for improved water management and ensuring that local and statewide interests are protected.

In spring 2009, the WWBWC hosted a Bi-state Groundwater Status meeting where hydrogeologists representing both states (OWRD/WDOE) met with WWBWC technical staff and discussed basin monitoring, aquifer trend analysis, and regulatory and enforcement tools by which the system can be better managed. In Washington the shallow aquifer is closed to further irrigation appropriations and has recently restricted the amount of water new exempt wells can utilize. In Oregon the shallow aquifer is still officially open to new well applications. However, new applications are being reviewed under a more detailed evaluation and additional scrutiny.

The WWBWC is also working with Oregon and Washington Water Trusts to create a bi-state water banking system in order to create 'cap-n-trade' mechanism. By creating a water banking system the intent is to create a system where new wells are required to mitigate for their use by purchasing mitigation credits through the Trusts. This system can help create revenue by which to help support the implementation of the ARSR program.

Progressive water management on the Oregon side of the basin is represented in the Umatilla Critical Groundwater Task Force[21] recently completed 2050 Plan[22] and its primary goal:

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[20] http://www.wallawallawatershed.org/
[21] http://umatillacounty.net/planning/Groundwater.htm
[22] http://www.co.umatilla.or.us/planning/Groundwater.htm

*"… ensure a coordinated, integrated response with maximum use of all water resources and to mitigate the effects of water declines impacting Umatilla County."(Umatilla County CGT, 2009)*

This forward thinking plan proposes the creation of water management districts, encouraging the construction and operations of aquifer recharge projects and working to create revenue streams from which funding can be acquired to implement more management projects in Umatilla County. The ARSR goals for the Walla Walla Basin follow those of the Umatilla County plan and have support for further development at the county level.

Water management efforts in both states have been working together to come up with programmatic solutions to addressing this bi-state hydrologic, biologic and economic issue. The Walla Walla Basin Aquifer Replenishment and Spring Restoration Program intends to build on all of these efforts by creating a coordinated bi-state approach to address the legal, design, distribution, timing, habitat, water quality and quantity issues that are anticipated in creating an aquifer and river system that is managed in a sustainable fashion. The overall goal, as illustrated in Figure 66, is to first *stabilize* the declining aquifer and then move toward *recovery* of lost storage.

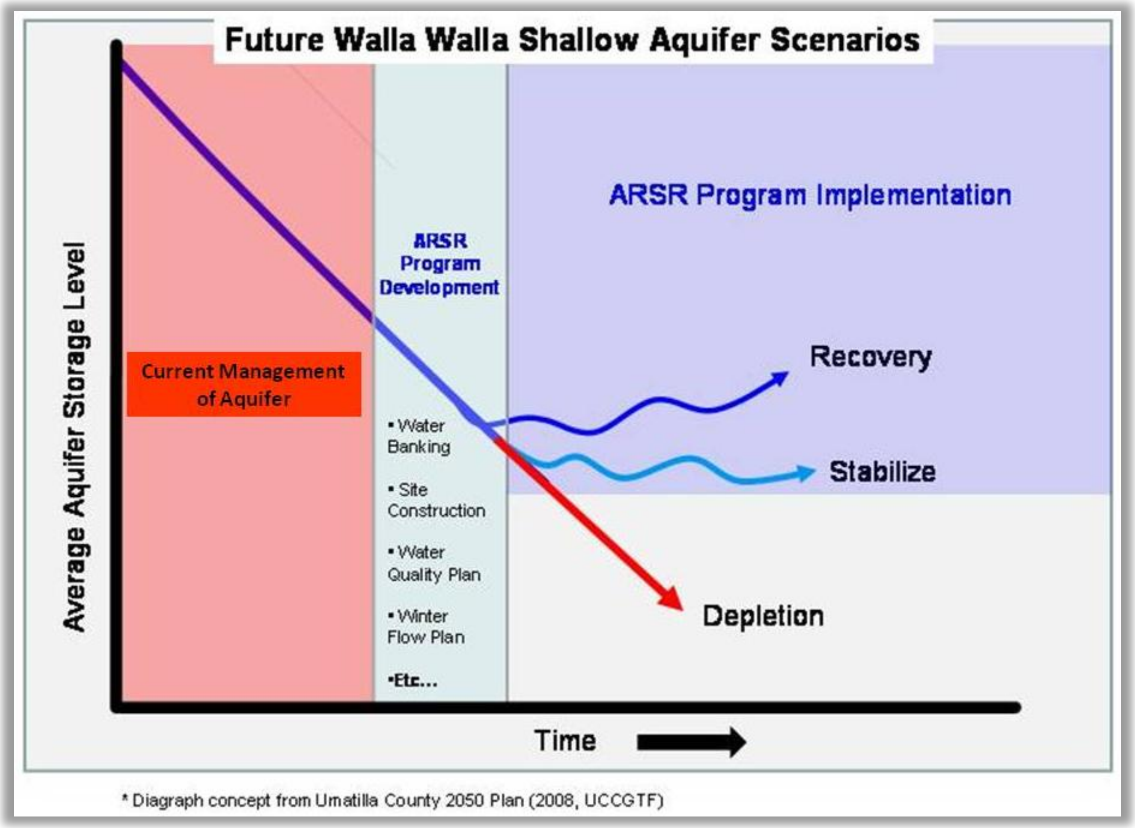

Figure 66. Conceptual Graph depicting goals of ARSR program

The goals of the ARSR program are to:

1. Build adequate recharge capacity to first stabilize and then recover shallow aquifer storage to historic levels**.**
2. Recovered groundwater storage will lead to the recovery of the natural springs which provide cool baseflow back to the Walla Walla River and its distributaries.
3. Whenever possible, refine and enhance current management of surface and groundwater capacities to support goal #1 (e.g. better management of Little Walla Walla River during non-irrigation season)
4. Work with water conservation efforts to design and build water systems that conserve water during times of scarcity and recharge water during times of abundance
5. Educate  the general public on the complexity of surface water-groundwater management in the Walla Walla Valley

This ambitious program will not be done unless the WWBWC and its partners pursue its creation and application. There are no state or federal programs that are set up to address this critical issue and without action now, the aquifer and related springs will continue to decline along with the fish and farms that depend on them. This program represents a clear and present need in the Walla Walla basin.

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* Electronic aerial photos of basin provided by: Dr. William Bowen California Geographical Survey (http://geogdata.csun.edu) 10907 Rathburn Avenue Northridge, CA 91326 william.bowen@csun.edu

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