SNWA Response to Bredehoeft Report and Exhibits

PRESENTATION TO THE OFFICE OF THE NEVADA STATE ENGINEER

Prepared by

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SNWA Response to Bredehoeft Report and Exhibits

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Pertaining to:
Groundwater Applications 54003 through 54021 in
Spring Valley
and
Groundwater Applications 53987 through 53992 in
Cave, Dry Lake, and Delamar Valleys

August 2011

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1.0 Report on the Hydrogeology of Proposed Southern Nevada Water Authority Groundwater Development (Bredehoeft, 2011a)

This section presents a rebuttal to the *Report on the Hydrogeolgy [sic] of Proposed Southern Nevada Water Authority Groundwater Development* (Bredehoeft, 2011a) (GBWN Exhibit 009). The Bredehoeft report presents unsubstantiated and invalid general conclusions. The reasons supporting this statement include the following:

- Oversimplification and inadequate examination of project operation and management, resulting in mischaracterization of potential impacts;
- Oversimplification and inadequate examination of local hydrogeologic conditions, and aquifer response dynamics, resulting in mischaracterization of potential impacts;
- Mischaracterization of availability of groundwater data;
- Mischaracterization and flawed evaluation of the effectiveness of monitoring programs as applied to this project;
- Substantial misrepresentation of the results and conclusions of models prepared to date, as described further in Watrus and Drici (2011);
- Overexaggeration and misrepresentation of projected significant harmful impacts resulting from the project operation;
- Failure to adequately consider adaptive management practices when evaluating potential impacts;
- Inadequate identification and examination of mitigation alternatives and remedies, resulting in inappropriate conclusions.

1.1 Bredehoeft (2011a) Invalid Conclusions

Bredehoeft incorrectly concludes that there will be significant harmful impacts associated with SNWA's proposed development. The conclusion is unsubstantiated and invalid based upon the broad over simplification of the project and misrepresentation of potential impacts. Bredehoeft inadequately examines and inaccurately evaluates local hydrogeologic conditions, projected model impacts, project operations, monitoring program effectiveness and adaptive management practices in arriving at his conclusion. The description by Bredehoeft of occurrence and degree of widespread significant harmful impacts are generalized and overexaggerated. The unsubstantiated statements in the conclusions do not reflect the practical reality of local hydrogeologic conditions, basic principles of well field system management and application of state of the practice groundwater monitoring, adaptive management practices and available remedies.

Bredehoeft (2011a) does not consider or examine variation in hydrogeologic conditions and pumping regimes which would influence the degree and timing of aquifer response in different areas of the project. He does not consider the degree of hydraulic connection between the specific pumping areas and areas of interest (streams, springs, wells, and phreatophytes). There is an assumption by Bredehoeft that once pumping begins it is continuously and not stopped or modified for hundreds of years negating proactive action or commonly applied operation and management practices. These points are addressed in detail in Sections 1.2 and 1.3.

Bredehoeft (2011a) on pages 7 and 10 fails to differentiate between non-consequential drawdown which occurs in the normal operation of a well, and significant harmful impacts, which occurs as a result of propagation of drawdown intersecting an area of interest to the degree that it has an unreasonable adverse effect. He also incorrectly assumes on pages 8-10 that all unreasonable adverse effects are largely irreversible, unavoidable, and can not be remedied, mitigated, or managed.

Bredehoeft (2011a) relies on inaccurate generalizations and mischaracterizations of model results as his basis for presenting effects. He does not identify what constitutes a significant harmful impact. He does not specify which streams, springs, or wells he expects to show significant harmful impacts or which water rights will be damaged. He does not present specific information on what degree of impact would occur under specific operating conditions and pumping regimes. He also discounts or dismisses available adaptive management practices and mitigation measures which can be used to prevent, minimize, manage or remedy any specific significant harmful impacts.

Bredehoeft (2011a) on pages 7 and 8 dismisses or discounts the effectiveness of monitoring using state of the industry practices. Bredehoeft's article (2011b) (GBWN Exhibit 011) presents a highly simplified theoretical example to inappropriately conclude that monitoring programs are ineffective at distances greater than 20 miles in the project area. Bredehoeft's conclusions derived from this simplified example are flawed and do not consider typical monitoring practices commonly used in the industry. It can be reasonably demonstrated, using Bredehoeft's example, that proper monitoring for significant pumping influence even at larger distances can be effective.

1.2 Oversimplification and Inadequate Examination of Project Operations Resulting in Mischaracterization of Potential Impacts

The planning, design, construction, and operation of the proposed project is a major investment for Southern Nevada Water Authority (SNWA). It is in SNWA's best interest to manage the water resources of the Project Basins and operate the project with a multigenerational timeframe horizon using best-management practices. This includes the management and minimization of unreasonable adverse effects on areas of interest as well as minimization of operational energy costs through well field management.

Bredehoeft (2011a) presents invalid conclusions based upon simplified operation and management of the production system. He assumes incorrectly that continuous pumping would occur and no proactive actions would be taken. This assumption in his analysis, results in unmitigated widespread significant harmful effects and damages throughout the region. This is stated without adequate consideration of project monitoring and adaptive management practices which would be utilized as described by Prieur (2011). He does not adequately consider that there are clear processes for mitigation action through the Nevada State Engineer (NSE), Federal stipulation agreements, Bureau of Land Management EIS requirements as well as other legal remedies. Project operations would be under the oversight of multiple regulatory agencies with close scrutiny throughout its lifetime.

There are a number of factors which are considered when operating a water-supply system. The operation of each well would consider water demands, well efficiency and performance, optimal pumping levels and associated energy costs, local hydrogeologic conditions including variation in seasonal water levels, aquifer response at varying pumping rates, and distance and degree of hydraulic interconnection to areas of interest. These considerations at each well would be evaluated in operating the project. The pumps would not just be turned on and pumped continuously for decades and centuries without using the appropriate best-management practices to optimize the system operations.

Water resource demands fluctuates seasonally as water usage varies. Spring Valley, DDC, Colorado River water, Las Vegas Valley, Las Vegas artificial recharge storage banked water and other established water banks are sources of system water which would be considered during overall project operations and management to derive the most appropriate distribution of source water. Use of the various sources of water will fluctuate throughout time depending on drought conditions. The SNWA project operations would weigh water availability, constraints on usage, seasonal water demand, cost, and energy conservation among other considerations to derive the optimal operation strategy and mixing of source water. Specifically within the Spring Valley and DDC project area, costs for operating the system, including each individual well, will vary.

In addition to minimizing potential impacts, there are energy related incentives to manage drawdowns. Increased drawdown in a well equates to higher energy costs for pumping. The amount, timing, and distribution of pumping would change as project demands change. Each well will have different energy costs associated with pumping based upon the local hydrogeologic conditions and depth to water. Some wells would be preferred for pumping over other areas under different conditions. It would be expected that pumping rates at a well would vary through the year based on these factors, project constraints and demands. There are also regular periods of maintenance for wells and segments of the system.

The various factors described above which are considered in the practice of managing project operations which determine pumping distribution, duration, pumping rate and schedule within the Project Basins and individual production wells are not adequately examined or considered by Bredehoeft. The pumping operations along with hydrogeologic conditions are directly linked to amount and timing of drawdown with distance from the pumping wells. Assuming continuous pumping at wells for decades and centuries is inaccurate and does not reflect the reality of operating a water system.

1.3 Oversimplification and Inadequate Examination of Local Hydrogeologic Conditions, and Aquifer Response Dynamics Resulting in Mischaracterization of Potential Impacts

1.3.1 Consideration of Local Hydrogeologic Conditions

Bredehoeft (2011a) assumes oversimplified hydrogeologic conditions which are not consistent with the project area. Bredehoeft (2011a) indicates widespread significant harmful impacts without adequately considering the role of specific hydrogeologic conditions of the project area including the degree of hydraulic interconnection between the pumping areas and areas of interest.

Understanding of local hydrogeologic conditions and response to pumping is important in developing and operating the production well network. The specifics of production-well selection, including local hydrogeologic conditions, location of areas of interest, and evaluation of relative hydraulic interconnectivity of those locations, are important in the evaluation of operational constraints and potential impacts. Monitoring with wells strategically located to assess aquifer dynamics and response with varying pumping regimes provide data to refine higher resolution predictive tools and provide information to optimize production well field operations. As more data become available, the certainty of the behavior of each well field improves, as well as the prediction and management of aquifer response.

Bredehoeft admits the importance of understanding hydrogeologic conditions and location of pumping in the aquifer system in other references. *"The dynamic response of the aquifer system is all-important to determining the impacts of development"* (Bredehoeft, 2002). *"Impacts can be quite different depending upon where the pumping is located in the system"* (Bredehoeft, 2011b). Yet in Bredehoeft (2011a), he ignores these factors in reaching his conclusions.

Specific pumping locations will be analyzed and scrutinized considering local hydrogeologic conditions, seasonal fluctuations of groundwater levels, and proximity to areas of interest. The interrelationship of hydraulic connection to local flow systems or perched systems at areas of interest to the production wells would be considered in: well design, including well depth, screened interval and length of gravel pack; system operation; monitor well placement and design; and data evaluation. Contrary to Bredehoeft's assumption, pumping wells will not be located randomly within the system and operated without considering local conditions and potential impacts.

Bredehoeft (2011a) does not mention or adequately consider the difference in hydrogeologic conditions between Spring Valley and DDC. Delamar and Dry Lake valleys have deeper groundwater levels where phreatophytes are not present or of concern. In Cave Valley, phreatophytes located near Parker Station in the northwestern portion of the valley and are supplied by groundwater recharge originating locally in the Eagan Ranges. In DDC, due to the depth of groundwater, springs are not hydrologically connected to aquifers where pumping is proposed. Springs present in DDC are generally mountain block springs not influenced by pumping. Examples include Grassy, Coyote, and Littlefield springs which are described in more detail in Prieur (2011) and SNWA (2009). A steep hydraulic gradient is present between southern Delamar Valley and central Coyote Spring Valley (Burns and Drici, 2011) which suggests the Pahranagat Shear-Zone and associated features control the hydraulic gradient, and would significantly attenuate or effectively prohibit drawdown propagation into Coyote Spring Valley.

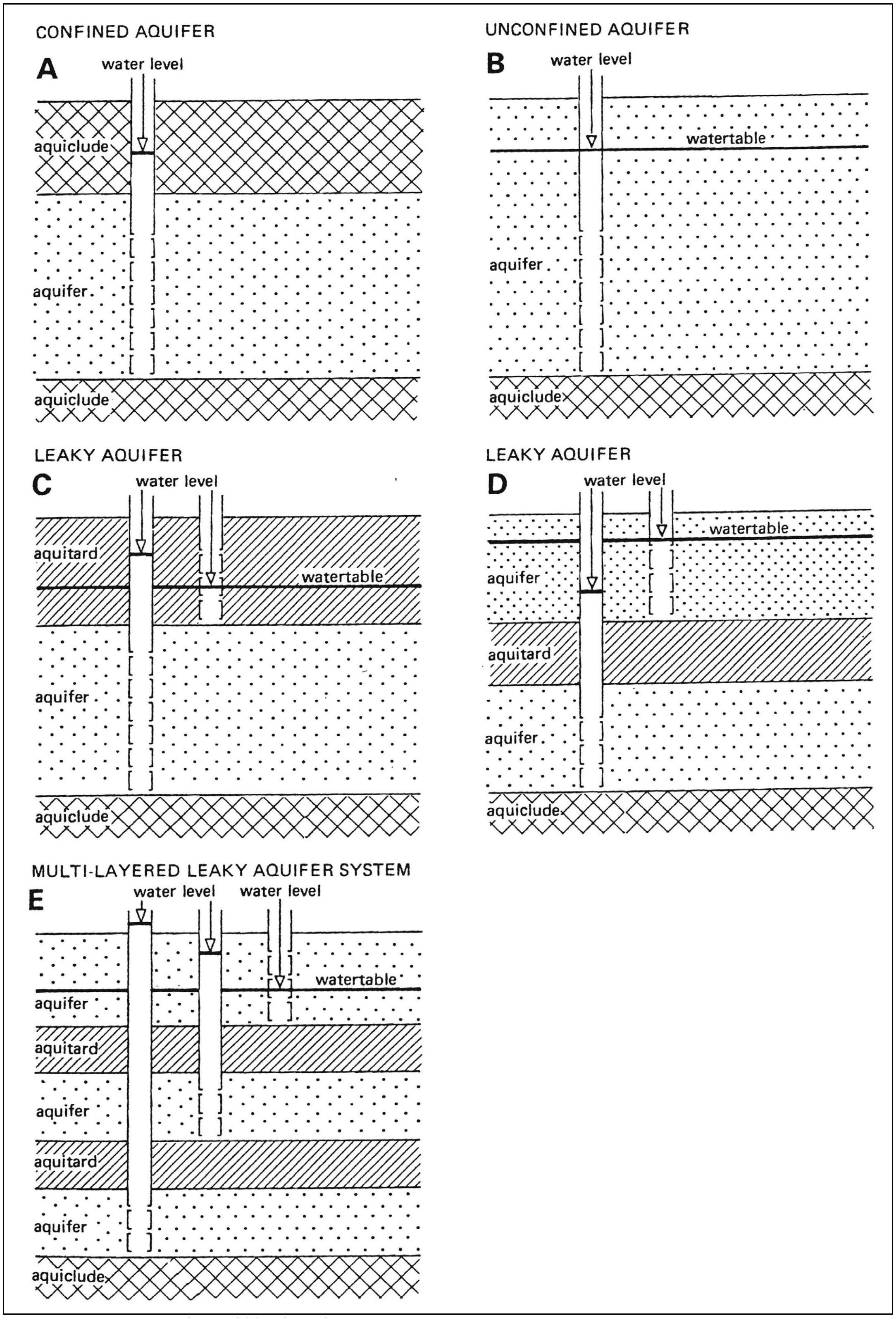
Bredehoeft (2011a), page 8 states that the "*current model suggests that there will be no impact on the Muddy River Springs from the pumping within the simulated 200-year planning horizon. However, we know from first principles that sooner or later the springs will be impacted by the pumping—the pumping will ultimately capture the spring flow.*"(Bredehoeft, 2011a). Bredehoeft specifically mentions potential future impact at Muddy River Springs from pumping in DDC. However, this is inconsistent in that Bredehoeft does not explain or quantify what "sooner or later" is or what degree of potential impact would ever be seen at Muddy River Springs.

He assumes continuous pumping and does not account for the hydrogeologic conditions in southern Delamar and northern Coyote Spring Valley which would limit changes in flux. He does not consider the steep hydraulic gradient from southern Delamar to north central Coyote Spring Valley. The change in hydraulic gradient across this low hydraulic conductivity zone, even if there were significant drawdown present in southern Delamar Valley, would be small. This would result in a minimal change in flux across the zone. So not only is there no response at Muddy River Springs predicted with the model, the hydrogeologic conditions would also act to retard significant impacts beyond 200 years.

Throughout the Dry Lake and Delamar valleys, numerous monitoring wells are in place. Additional monitor wells are present in northern and central Coyote Spring Valley. These locations would act as early warning and identify a propagation of significant drawdown. The monitoring network in Delamar Valley would be effective in detecting significant drawdown, which would need to be present in order to possibly have a future influence on Muddy River Springs. The effectiveness of monitoring at distances greater than 20 miles is described in Section 2.0 of this report. There is no other significant planned pumping other than SNWA's that would be occurring in Delamar Valley to influence the baseline data collected by the monitoring network.

Spring Valley is predominantly a closed basin with limited discharge from southern Spring Valley into Hamlin Valley (Burns and Drici, 2011). Groundwater flows from recharge areas within the mountain block and on the alluvial fan to the groundwater discharge areas on the valley floor. Examples of various local hydrogeologic conditions observed in Spring Valley are presented in Figure 1. Each of these conditions would respond differently to pumping, yet Bredehoeft (2011a) never considers this. SNWA would consider variations in local hydrogeologic conditions in production well location, design and operation, as well as monitor well placement and design.

Varying hydrogeologic conditions present in different parts of the project area must be considered when evaluating the operation of the project and its potential effects. Results from monitoring programs will define the conditions in a more detailed manner than what is represented in the current regional groundwater flow model and be used to refine predictive tools.



Source: Kruseman and De Ridder (2000)

Note: A. Confined aquifer; B. Unconfined aquifer; C. and D. Leaky aquifers; E. Multi-layered leaky aquifer system

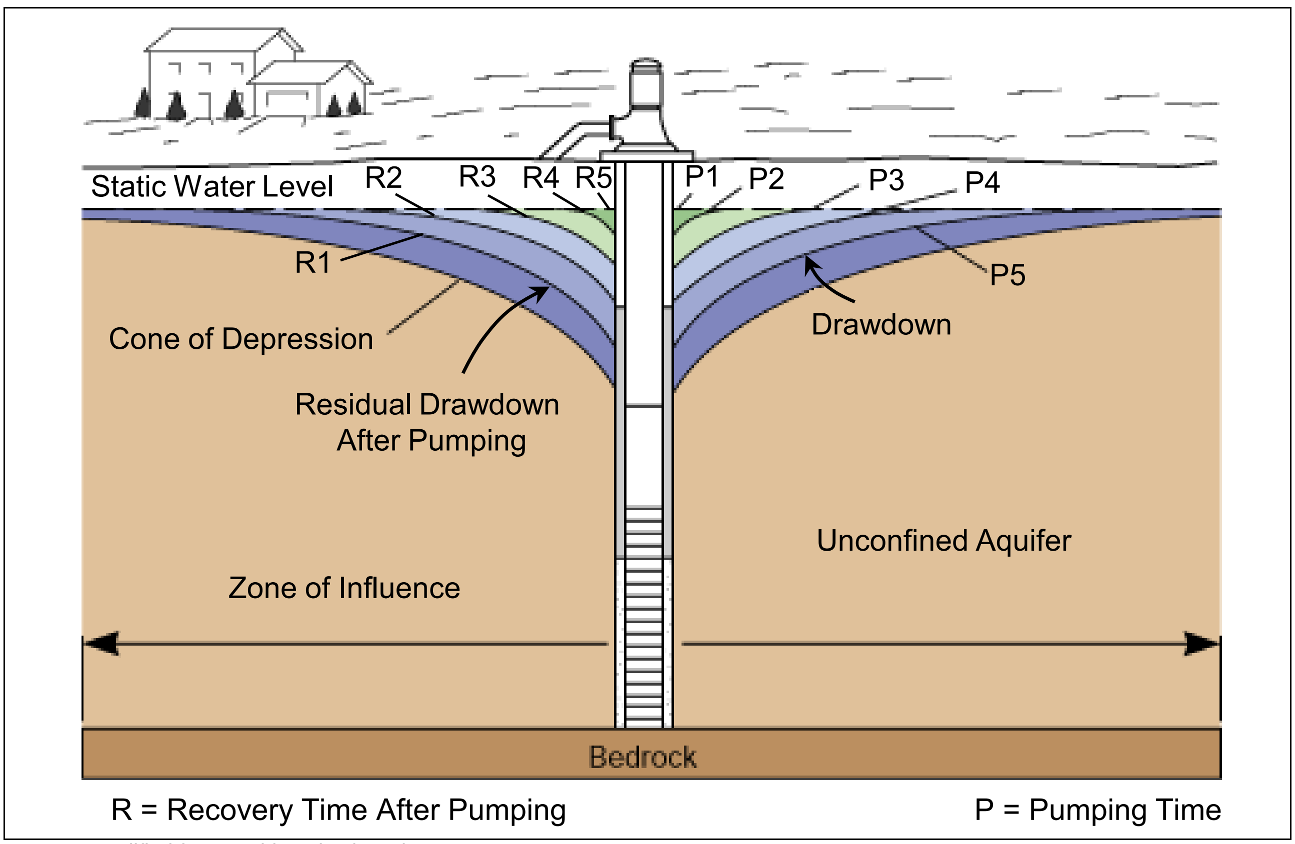
Figure 1
Examples of Different Types of Hydrogeologic Conditions in Spring Valley

1.3.2 Overview of Well Hydraulics and Aquifer-Response Dynamics

The aquifer response to pumping at each well site and the combination of different well sites is important. Bredehoeft simplifies the aquifer response without consideration of local hydrogeologic conditions or modification of pumping regimes using monitoring results, predictive tools and adaptive management practices.

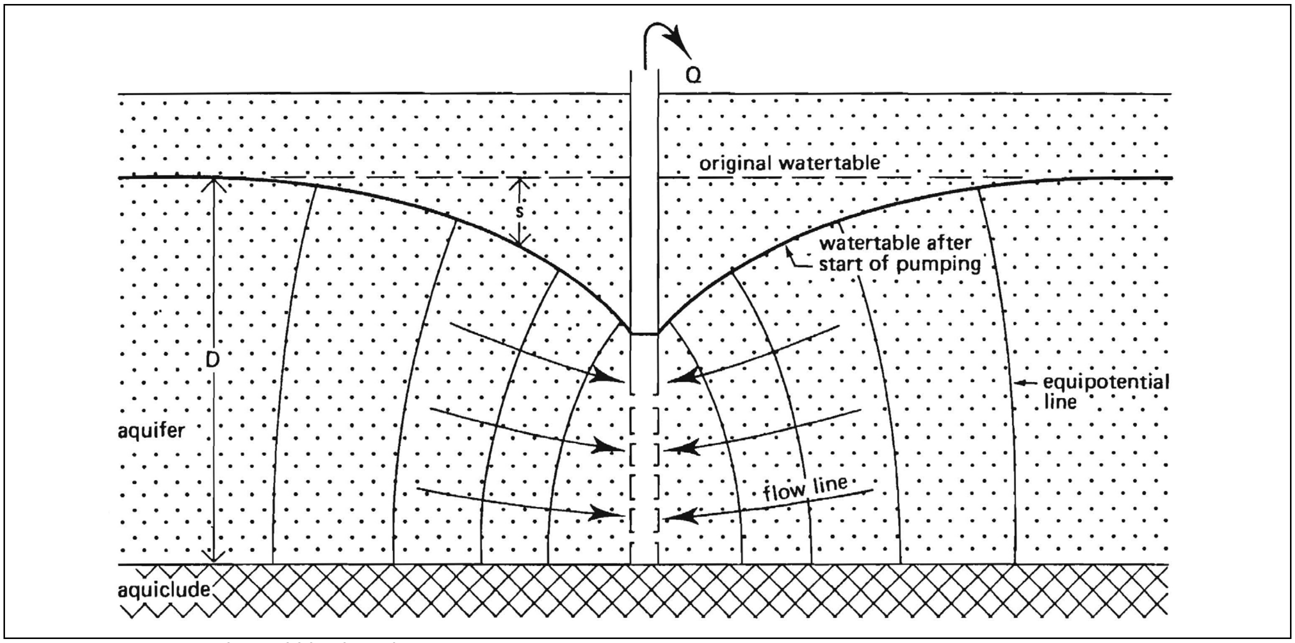
A brief discussion is presented below which provides a basic primer on well hydraulics; how drawdown is created, changes with time and distance, recovery after pumping decreases or stops, and how drawdown relates to areas of interest.

A well which is pumped, responds by the water level dropping within the casing and screen. As pumping continues a cone of depression develops and expands around the well. Figure 2 illustrates the expansion of the cone. The rate of change in drawdown within the cone decreases with time logarithmically. The amount of drawdown also decreases logarithmically with distance from the well. So at the same pumping rate, the greatest amount of drawdown change occurs early and decreases logarithmically with time. The greatest drawdown is near the well and there is logarithmically less drawdown with distance from the well to its radius of influence where there is no drawdown. Groundwater flows to a pumping well as illustrated in Figure 3. A plan view of the cone of depression and groundwater flow in the vicinity of the cone of depression is presented in Figure 4.



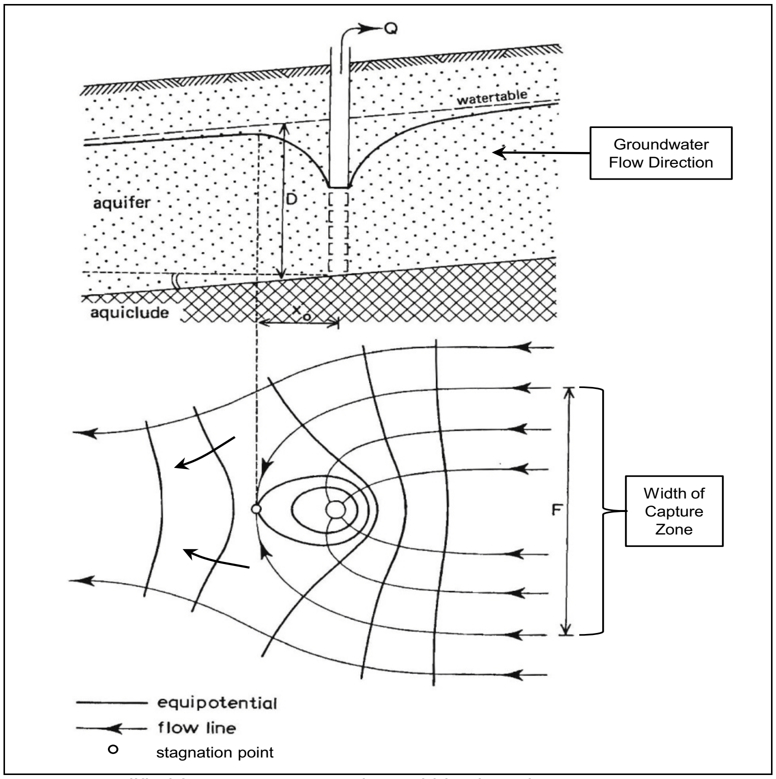
Source: Modified from Buddemeier (2000)

Figure 2
Simplified Water-Table Drawdown and Recovery after Pumping at Different Times



Source: Kruseman and De Ridder (2000)
Note: Q = Discharge; s = Drawdown; D = Aquifer Saturated Thickness

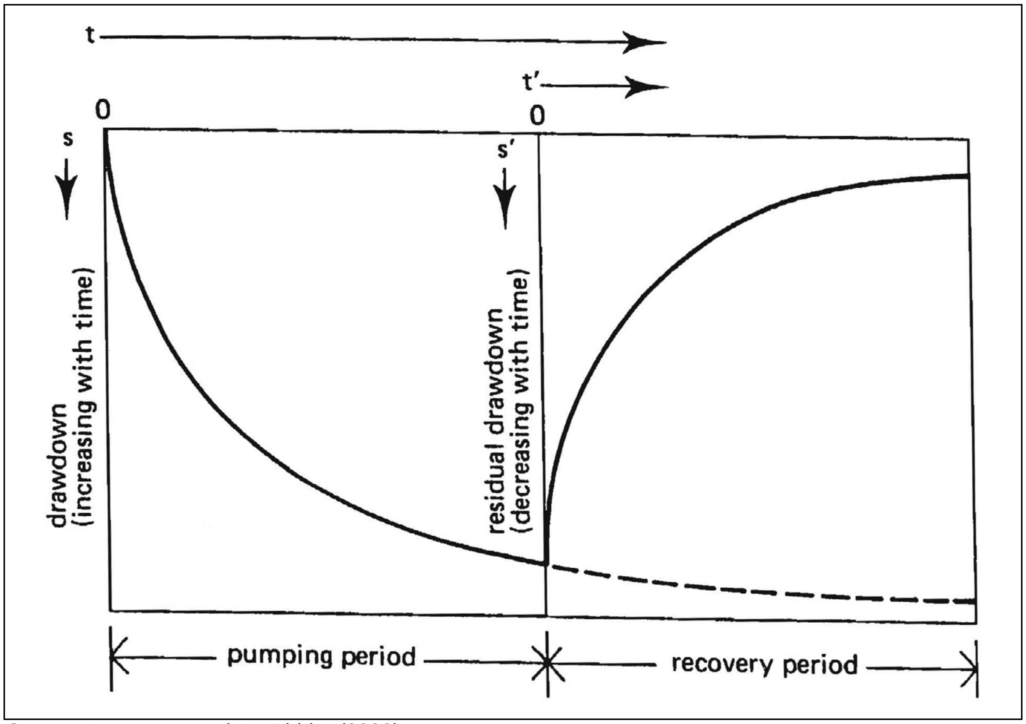
Figure 3
Cross Section of a Pumped Unconfined Aquifer



Source: Modified from Kruseman and De Ridder (2000)

Figure 4
Cross Section and Plan View of a Pumped Unconfined Aquifer

After pumping is stopped, either short or long term, the well immediately begins to recover. The rate of change of the increase in water levels during recovery within the cone of depression is faster in the beginning of recovery and decreases logarithmically with time in a manner generally opposite to pumping as illustrated in Figure 5.

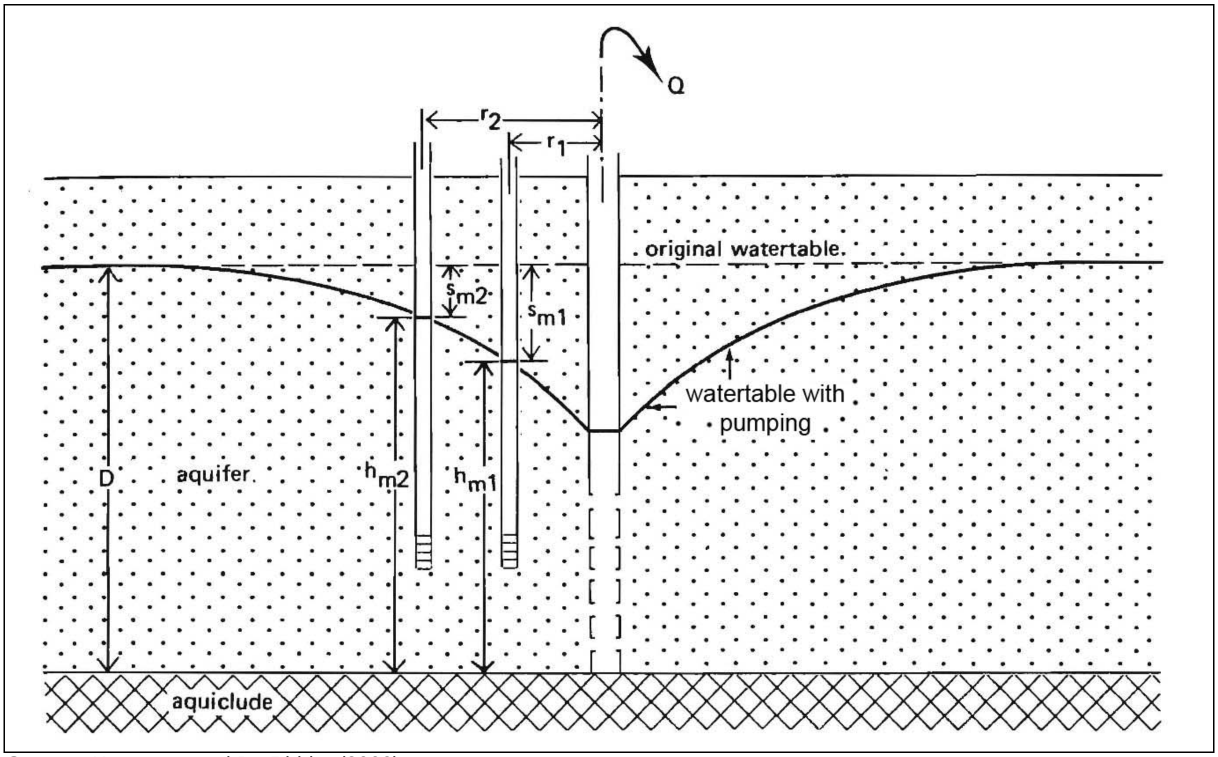


Source: Kruseman and De Ridder (2000)
Note: t = Time; t' = Time After Pumping Stops; s = Drawdown; s' = Residual Drawdown

Figure 5
Drawdown During Pumping Period and Residual Drawdown During Recovery (Pumping Stops at Time = t')

The hydrogeologic relationship between the pumping location and areas of interest is important in evaluating and determining well locations, operational pumping rates, and frequency of pumping. The relationship includes distance, degree of hydraulic connection, and aquifer properties between the pumping location and area of interest.

Monitor wells can be used to observe water levels within of the cone of depression as illustrated in Figure 6. Additional monitor wells may be located outside the cone of depression between the pumping well and areas of interest to provide early warning and assessment of changes in water levels. Monitor wells are strategically located and designed considering local hydrogeologic conditions, design of pumping wells and hydrogeologic conditions at the areas of interest. Hydrographs showing water levels with time are prepared to evaluate natural and pumping induced changes and trends in water levels. Aquifer properties such as transmissivity and storage values can be derived from the amount of change and rate of change of drawdown in the monitor wells within the cone of depression at different pumping rates. The aquifer properties can be used to predict aquifer drawdown response at various times and distances from pumping wells and at different pumping rates.



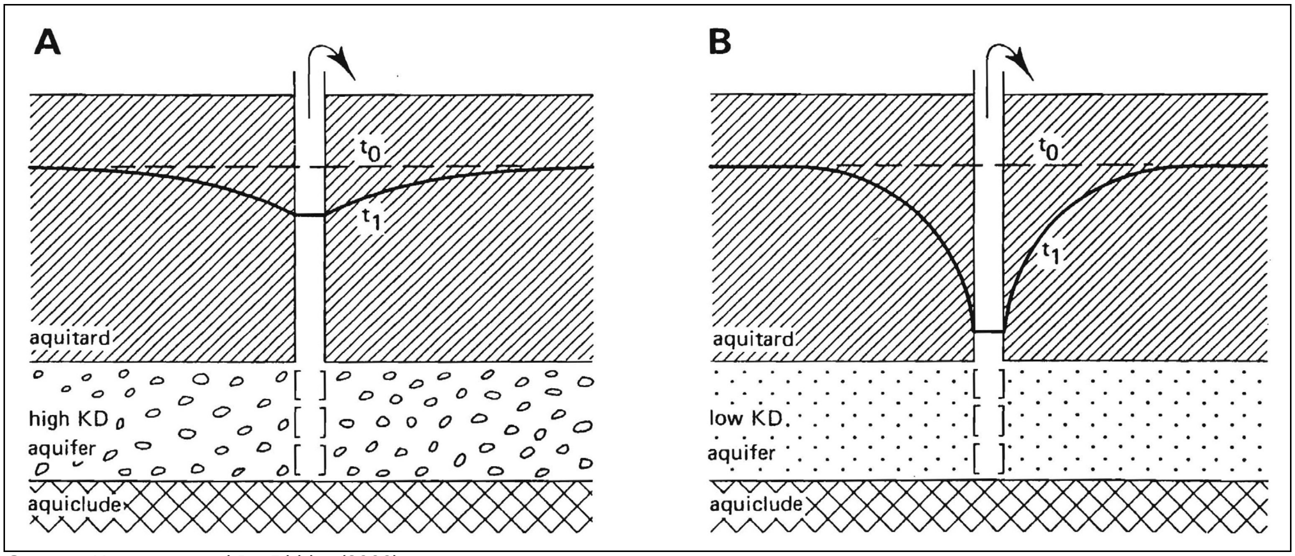
Source: Kruseman and De Ridder (2000)
Note: r = Distance From Pumping Well; s = Drawdown; h = Groundwater Level Elevation; D = Aquifer Thickness; Q = Discharge

Figure 6
Cross Section of a Pumped Unconfined Aquifer with Monitor Wells

Data gathered from pumping can be used to increase the certainty of the predicted drawdown and recovery responses at different pumping rates and durations. The data can be used to refine a higher resolution flow model in the vicinity of the pumping areas and other predictive tools which consider variations in local hydrogeology. These tools would provide more certain results than current more generalized lower-resolution models. Future change in drawdown with distance and time can be calculated using the aquifer properties and rate of change observed in the monitor wells.

The shape and amount of drawdown observed at any point within the cone of depression is dependent upon the pumping rate, duration of pumping, aquifer properties (transmissivity and storativity or specific yield) and boundary conditions. The cone may be elongated or prevented from expanding in a direction depending on how the aquifer properties vary in each direction. Examples of the difference in the general shape of the cone of depression in low and high transmissivity materials is presented in Figure 7. Each pumping well will be evaluated for performance and local aquifer properties.

Well performance and aquifer response monitoring in the vicinity of the pumping well, especially during earlier portions of the well startup, is conducted to increase understanding of the aquifer dynamics. This information is used to determine optimal pumping rates and schedule of pumping. Longer term data collection will provide response data for higher resolution flow modeling with more site-specific aquifer property data and boundary conditions to predict drawdown and cumulative effects between wells. Results are then used to refine production well operations.



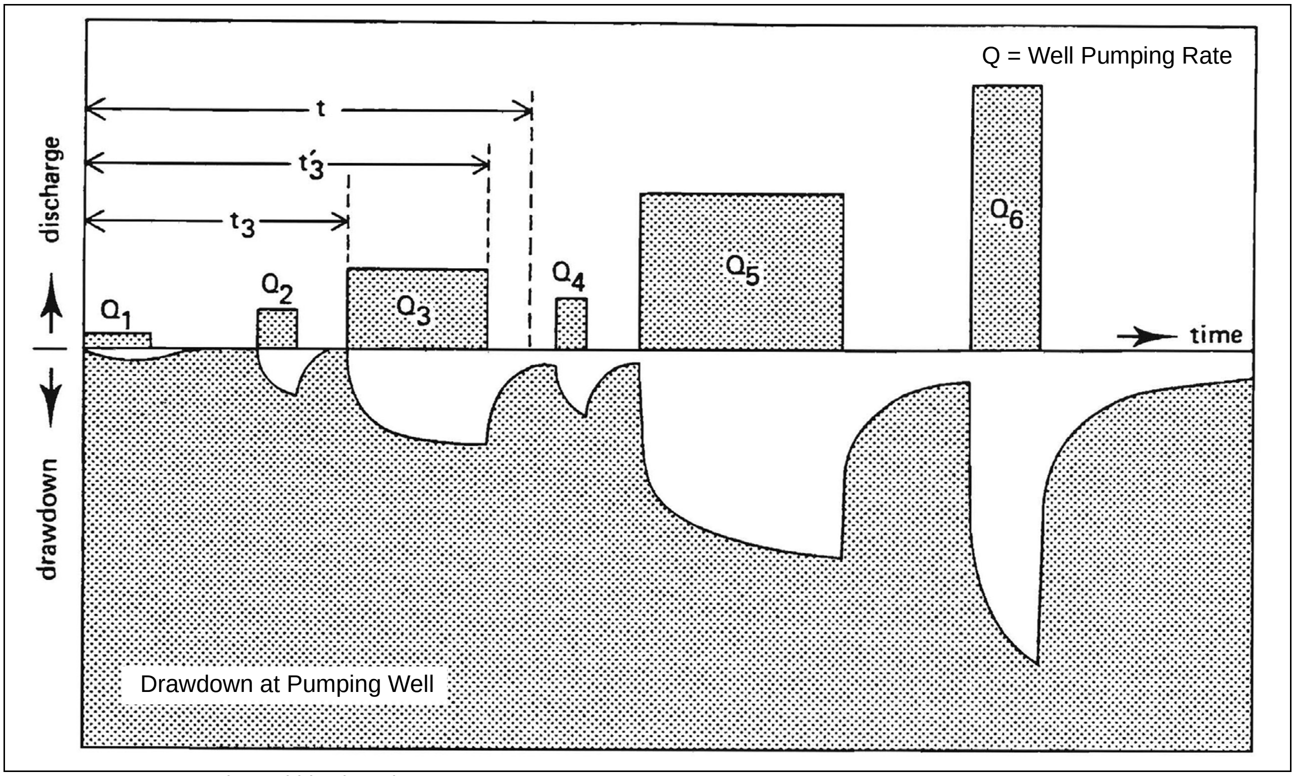
Source: Kruseman and De Ridder (2000)
Note: KD = (Hydraulic Conductivity) (Saturated Thickness) = Transmissivity; t_0 = Prior to Pumping; t_1 = Time During Pumping

Figure 7
Cone of Depression at a Given Time T In:
(A) an Aquifer of High Transmissivity; (B) an Aquifer of Low Transmissivity

Cycling wells and varying pumping rates based on seasonal demand and local hydrologic conditions can manage drawdown in the vicinity of the well. Current technology exists and is being used by SNWA to provide continuous monitoring with real time operation data to be able to dynamically manage and optimize a groundwater development operation. Well pumping rates and pumping schedules for each well will be evaluated. Rotation of pumping, cycling wells and optimal spacing are all considerations for well operations which can delay, eliminate, or minimize drawdown at a particular distance. An example of intermittent pumping with varying rates and effects on drawdown is presented in Figure 8.

An example of potential pumping optimization involves increasing pumping rates at alluvial fan wells in Spring Valley during reoccurring periods of large seasonal recharge pulses from spring snowmelt. A hydrograph of continuous and periodic groundwater levels at Monitor Well SPR7007M located on the alluvial fan near Swallow Canyon is presented in Figure 9. The pumping rate at a production well at this location could be significantly increased during the recharge period between June to October which corresponds to the peak water demand in southern Nevada and reduced during the remainder of the year. This is one example of the type of potential considerations for well and system operations.

Evaluation of local hydrogeologic conditions associated with potential production well locations and areas of interest, siting and design of pumping wells in consideration of those conditions, analysis of aquifer response in the vicinity of the production wells, and pumping optimization based upon site specific conditions and constraints are considerations which Bredehoeft (2011a) does not adequately examine and properly evaluate in deriving his conclusions.



Source: Kruseman and De Ridder (2000)

Figure 8
General Drawdown and Recovery Behavior from Intermittent Pumping with Varying Discharge Rates

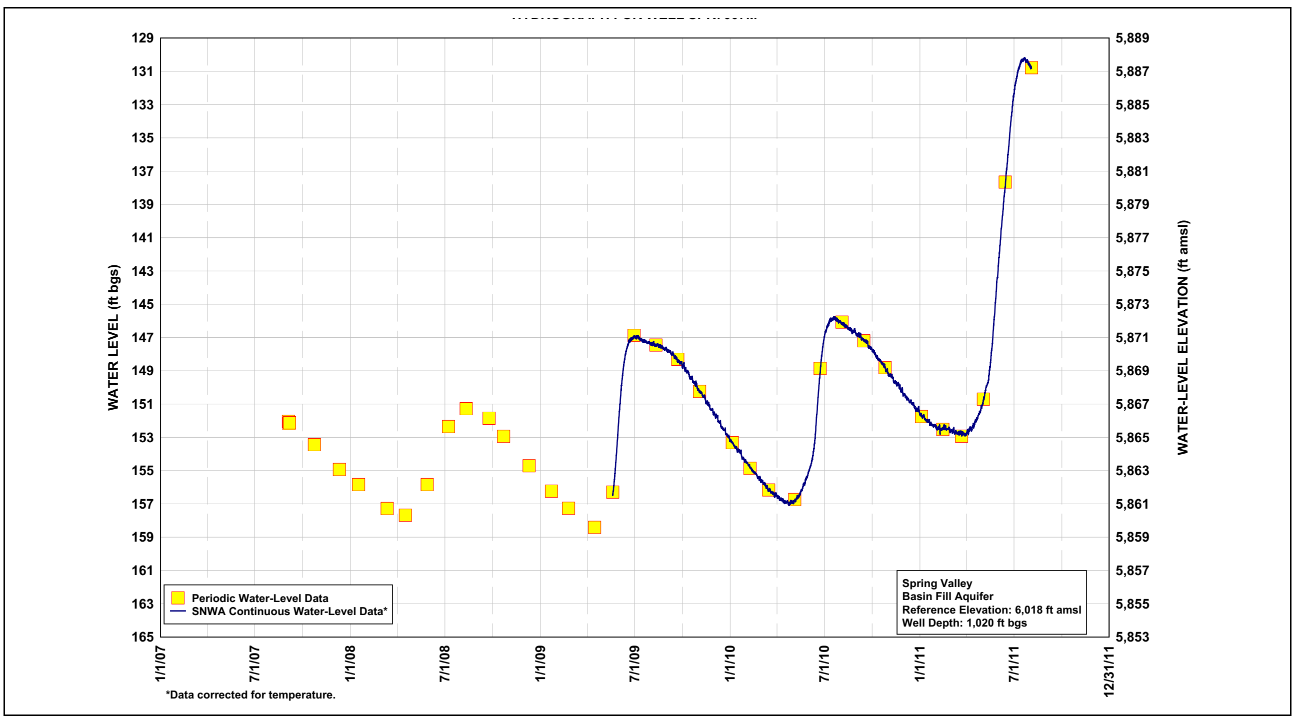


Figure 9
Hydrograph for Well SPR7007M

1.4 Availability of Groundwater Data

Bredehoeft (2011a) page 5, states "*Only a handful of wells with continuous well hydrographs exists in the region.*" While this statement does not appear to directly relate to the conclusions derived by Bredehoeft, it is a mischaracterization of current groundwater, stream and spring monitoring data associated with Spring Valley and DDC.

At this time, there are 54 monitor wells in place specific to the monitoring plans in Spring Valley and DDC with continuous recording instrumentation at 23 locations. Thirty-three (33) springs are currently being monitored with continuous discharge or piezometer instrumentation in place at 19 locations. Installation of 12 additional wells with continuous instrumentation is planned in the future prior to project initiation. These wells and springs, coupled with numerous stream discharge continuous gages, provide an expansive baseline hydrologic monitoring program. Data from the Spring Valley and DDC programs are submitted quarterly to NSE and USGS for publication on their respective publicly accessible databases. Continuous and historic hydrographs for monitoring locations in Spring Valley and DDC are included in annual reports submitted to the NSE.

Additional regional data in the vicinity of the project area is collected in Nevada through joint funding agreements with SNWA, USGS, and NSE. Regional data is also collected in western Utah through a joint funding agreement with SNWA and the Utah office of USGS. Other data collection efforts are ongoing in the project area by USGS and the Utah Geological Survey. An example of hydrologic studies in the region include the SNPLMA hydrologic study led by Dr. David Prudic of UNR, which studies surface and groundwater interaction in and near Great Basin National Park. The study included evaluation of hydrogeologic conditions of in the vicinity of Big Springs. The preliminary study results were summarized at a public meeting in Ely on August 16, 2011 (Prudic, 2011).

1.5 Identification and Examination of Mitigation Alternatives

Bredehoeft (2011a), p.8 again mischaracterizes model results as he states the "Given that the models all project similar results, some or all of these measures will need to be considered." As discussed in Watrus and Drici (2011), widespread impacts are not the consensus from all models. Bredehoeft dismisses any form of mitigation, does not consider adaptive management practices, or remedies for specific impacts which are available. Examples include modification and optimization of well field operations, artificial recharge of excess peak streamflow or rejected recharge, and use of SNWA non-project surface and groundwater water rights for mitigation. He does not consider the lowering of pumps and deepening or replacement of wells which may be impacted. He also does not consider alternative mitigation measures available for springs such as discharge flow augmentation or other measures such as habitat restoration, improved and/or modified grazing and irrigation practices to benefit target species and habitats as explained in Marshall and Luptowitz (2011).

Rejected recharge and excess flood streamflow in Spring Valley are discussed in Rush and Kazmi, 1965. Substantial volumes of runoff have been documented reaching Yelland Dry Lake and to a lesser degree Baking Soda Flats. A photo of Yelland Dry Lake taken in July 2011 is presented in Figure 10. SNWA has performed volumetric estimates of water volume present on Yelland Dry Lake over several decades using satellite imagery. The estimated volume in just Yelland Dry Lake in July

Figure 10
Yelland Dry Lake Photo from Taft Creek (July, 2011)

2011 was greater than 10,000 acre feet. Excess peak flows as observed this year demonstrated that significant water above existing rights flows to the playa and evaporates. Excess stream flows are present during wet years in the Schell Creek and Snake Ranges. Representative examples of excessive stream discharge over time are presented using Bassett Creek and Swallow Canyon stream discharge hydrographs (Figures 11 and 12). A certain portion of the excess water depending upon legal and technical constraints, could be effectively intercepted and artificially recharged using infiltration basins and trenches in certain target areas.

It may be possible that portions or the entirety of a valley's well network is shut down for a period of time to allow for recovery. Bredehoeft (2011a) example of having an extended period of shut down during project operation is not out of the question if operational data indicate that it is the appropriate action. Again, he assumes that no adaptive management actions will be taken during the life of the project in deriving his conclusions. It is in SNWA's best interest to manage the project in a responsible manner with multigenerational timeframes in mind. It is a goal of the program to operate in an efficient manner to avoid, minimize and/or manage impacts.

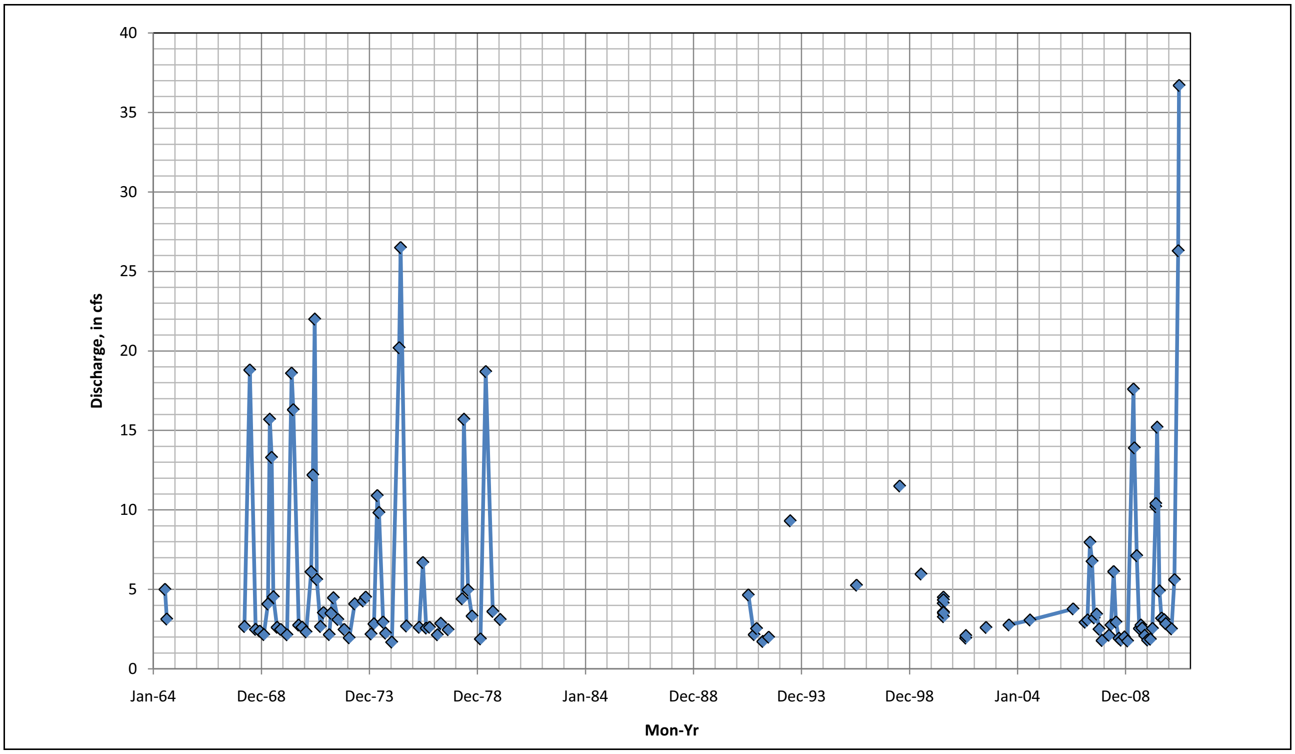


Figure 11
Bassett Creek Discharge Measurements 1964-2011

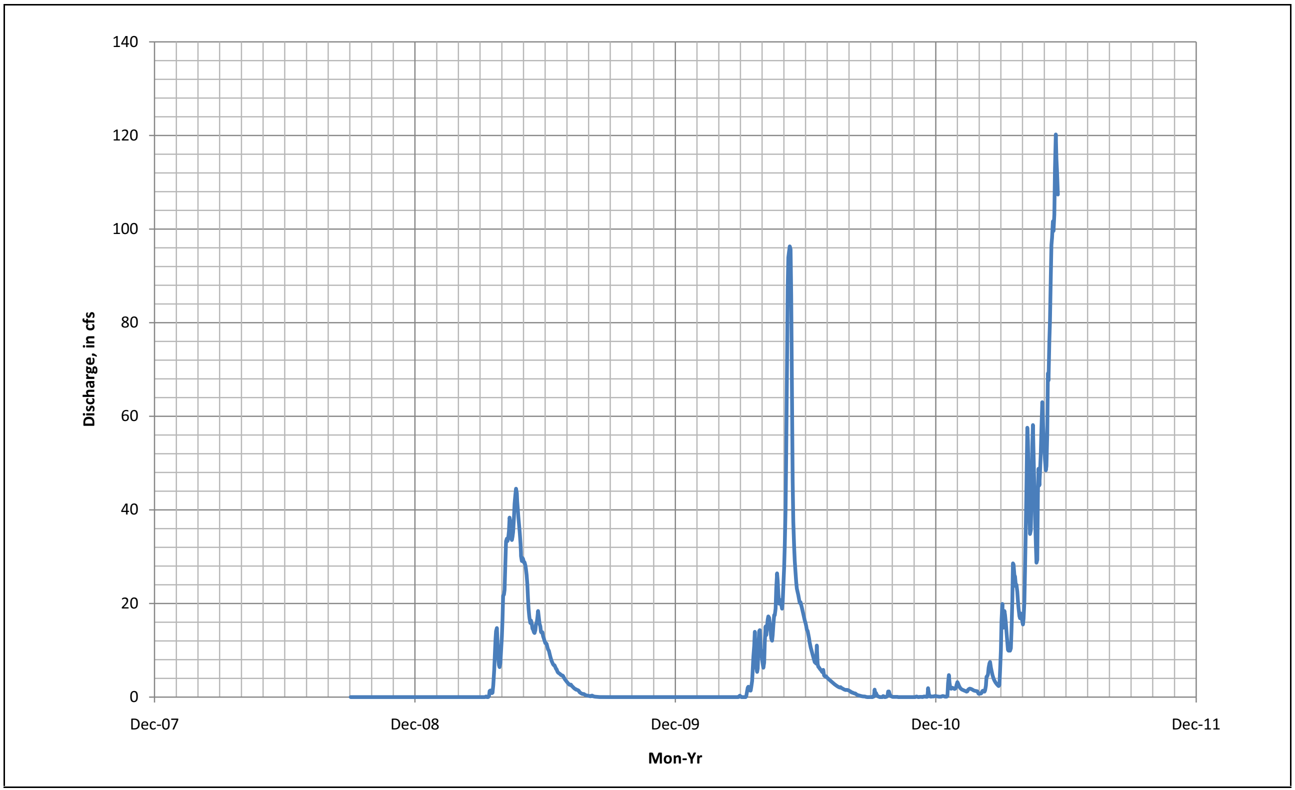


Figure 12
Swallow Canyon Discharge 2008-2011

2.0 Effectiveness of Monitoring Programs (Bredehoeft, 2011a) and Monitoring Regional Groundwater Extraction: the Problem (Bredehoeft, 2011b)

Bredehoeft's (2011a and b) expert report and article inappropriately discount or dismiss the ability of monitoring programs to identify significant influence of pumping at larger distances (greater than 20 miles) from production wells. Bredehoeft, in addition to discounting or dismissing the effectiveness of monitoring, also inappropriately dismisses the use of adaptive management in the operation of a groundwater development program. This is done even though the use of groundwater monitoring and adaptive management are best industry practices. He also fails to examine the effective utilization and local understanding of hydrogeologic conditions which are incorporated into monitoring and operating plan development.

Monitoring Regional Groundwater Extraction: the Problem Bredehoeft (2011b) (GBWN Exhibit 011) discusses the ineffectiveness of monitoring at distances greater than 20 miles. Bredehoeft presents and utilizes an overly simplified hypothetical model that is inapplicable to real-world conditions and does not reflect the monitoring program present in the Project Basins. The hypothetical example is designed in a manner to support his predetermined conclusions that monitoring is ineffective and recovery periods are prolonged. The example is set up to fail by design.

The example has no basis related to the conditions of the Project Basins and project design and operations. The problem example is overly simplified to the point that it does not reflect reality. It does not reflect how an actual monitoring program would be implemented or how the results of the program will be used to modify pumping operations in the project area through adaptive management. Even with the limitations and inaccuracies, the hypothetical example he presents actually contradicts his conclusion and is shown to support the case that monitoring and adaptive management is effective.

The SNWA hydrologic monitoring program has three general phases: (1) establishing baseline conditions, (2) monitoring associated with the production well network configuration; and (3) data collection during operation. The hydrologic monitoring program is currently in place and collecting data on baseline conditions where natural aquifer responses are documented over an extended period of time. The expansive network of monitor wells, spring piezometers, spring and stream discharge gaging stations, and precipitation stations are recording hydrologic system response associated with natural variations in hydrology such as wet and dry periods.

Very limited pumping is currently occurring in the Project Basins, so influence on the monitoring network from existing pumping is limited when establishing baseline conditions, natural trends and understanding behavior at network monitoring points. Hydrographs from the monitoring network locations are compared for similar or varying behavior in order to group wells with similar or varying response. Natural lag times of recharge pulses and climate variations are evaluated. Over time certain wells are identified which behave similarly and show similar response to outside influences.

During pumping operations, significant deviation outside the normal range of water levels in a monitor well would provide an alert to evaluate the cause of the deviation. Comparison of data from other monitor wells which historically behaved the same way would be evaluated. Network wells closer to pumping centers than those at a farther distance would be compared. Wells within the area of influence of pumping would deviate from natural conditions compared to wells outside the influence of pumping. The larger the drawdown from pumping at the monitoring location, the greater the deviation from natural behavior. Drawdown closer to the pumping center along the flow path would be greater than at a distance. In the Bredehoeft (2011b) hypothetical example, there is no monitoring program in place.

An evaluation of the Bredehoeft's (2011b) theoretical example is presented below. The example, reproduced with comments in Figure 13, oversimplifies the aquifer dynamics, recharge, and pumping operations, and discharge areas of interest. Bredehoeft does not fully disclose his assumptions but seems to assume a closed system with homogenous isotropic conditions with recharge only occurring at one end of the valley (no other recharge near the spring or other areas in the valley). The example assumes consistent aquifer properties between the pumping well and spring. The example assumes continuous pumping at 44,800 gpm (100 cfs) from one pumping center for 230 years. It assumes that the pumping intercepts flow to the spring and there is obvious hydraulic connection between the pumping well and spring. There are no monitoring points between the pumping well and spring with the exception of an observation well mentioned in the article 48 miles downgradient of pumping (2 miles upgradient of the spring).

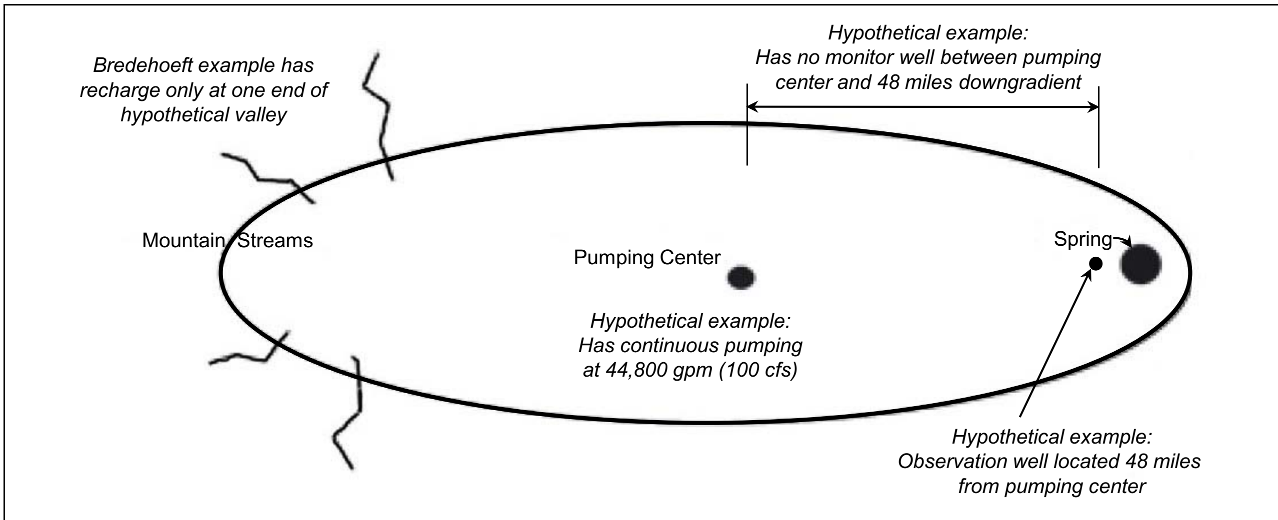


Figure 1. Schematic plan of the hypothetical valley. The pumping center is 50 miles from the spring.

Source: Modified from Bredehoeft (2011b), Note: Italics and observation well added to original figure.

Figure 13
Hypothetical Spring Impact Example Provided by Bredehoeft (2011b)

In presenting a similar type of example in Bredehoeft and Durbin (2008) (GBWN Exhibit 012), it is stated in the article that "*We are not arguing that this is a rational policy, rather we are illustrating a point.*" Bredehoeft also states the simplicity of the example clearly in the article "*I introduce a model of a hypothetical groundwater system. I am doing this with the full awareness that the results are unique to the model. On the other hand the model is quite simple and contains parameter values typical for many aquifers. I am going to generalize from the results of my model, knowing full well the limitations of my analysis and the limitations of generalizing from model results*" (Bredehoeft, 2011b). The readers of Bredehoeft (2011b) and Bredehoeft and Durbin (2008) should use caution in applying the results and conclusions derived from the hypothetical example presented by Bredehoeft (2011b) and Bredehoeft and Durbin (2008) to real world situations due to the simplistic and unrepresentative nature of the example. It would not be appropriate for decision makers to apply the results of this simple model to the complex systems and hydrogeologic conditions present at Spring, Cave, Dry Lake, and Delamar valleys.

One problem with the hypothetical example is that Bredehoeft does not examine the aquifer response in the context of a realistic industry-standard monitoring network. His example presents an observation well 2 miles upgradient of the spring (48 miles downgradient of the pumping center) to show similarity of response in the well and spring. Bredehoeft fails to use observations at this well as an early warning to implement a management action as would occur through a clearly established process in the monitoring and mitigation plan for the Project Basins. At that hypothetical observation well, a drop of water level outside the range of natural fluctuation is present after approximately 80 years. He fails to mention that other regional monitor wells outside the area of influence of pumping would not observe the drawdown caused by pumping. As discussed earlier, it is common industry practice to have multiple monitor wells in an aquifer system which have similar behavior in hydrographs in response to regional natural variations. Pumping impacts would be additive to natural fluctuations. Wells within the influence of pumping would deviate in behavior significantly over time compared to the monitor well hydrographs outside the influence of pumping, thereby providing a signal of pumping impact and not natural variation. The more significant the effect of pumping, the greater the deviation from natural fluctuation and clearer the difference would be.

While minor higher frequency events and short-term or seasonal variations in pumping effects may be filtered out by the system at long distance, long-term changes and effects of pumping can be observed. Bredehoeft (2011b) states "*At a distance of 50 miles in many aquifers, one can observe long period phenomena; even seasonal impacts may be filtered out…long term changes in pumping can be observed.*" Bredehoeft admits that monitoring within 4 miles would have a high probability of detecting impacts from pumping. At greater distances, even though seasonal and high frequency events may be filtered out, long-term pumping effects would be still be observed, so monitoring is effective even at greater distances.

A series of monitor wells between the pumping center and Bredehoeft's example spring would show greatest drawdown near the pumping center and logarithmically decreasing drawdown with distance to the spring. The drawdown from hypothetical pumping is observed first at the pumping center and expands with distance logarithmically with time. Calculations using similar theoretical aquifer property parameters and continuous pumping rate utilized in Bredehoeft's hypothetical example would indicate, after 100 years of continuous pumping approximately 56, 26, and 14 ft of drawdown at monitor wells located at distances of 10, 20, and 30 miles from the hypothetical pumping center.

All significant enough to provide an early warning signal well for an appropriate consultation or management action well in advance of the 230 year period indicated in hypothetical example.

In Bredehoeft's example, his use of just one hypothetical observation well at 48 miles from the pumping center provides a clear early warning indictor of impacts of long term pumping as demonstrated in Figure 5 of GBWN Exhibit 011. This hypothetical well, by itself, provides an early warning by an increasing deviation of groundwater levels from natural range of behavior observed in the baseline period. This is evident at a sooner time frame than waiting for the hypothetical 10 percent spring response to initiate a management action. Locating even one monitor well as far away as 48 miles downgradient of pumping provided up to a 100 year advanced alert to impacts on the spring versus having no monitoring. If pumping was stopped or modified during the early warning period as is illustrated in Figure 14, it would have resulted in a smaller decrease in springflow than waiting to take action at 230 years with no monitoring. This is an example of effective monitoring and active adaptive management.

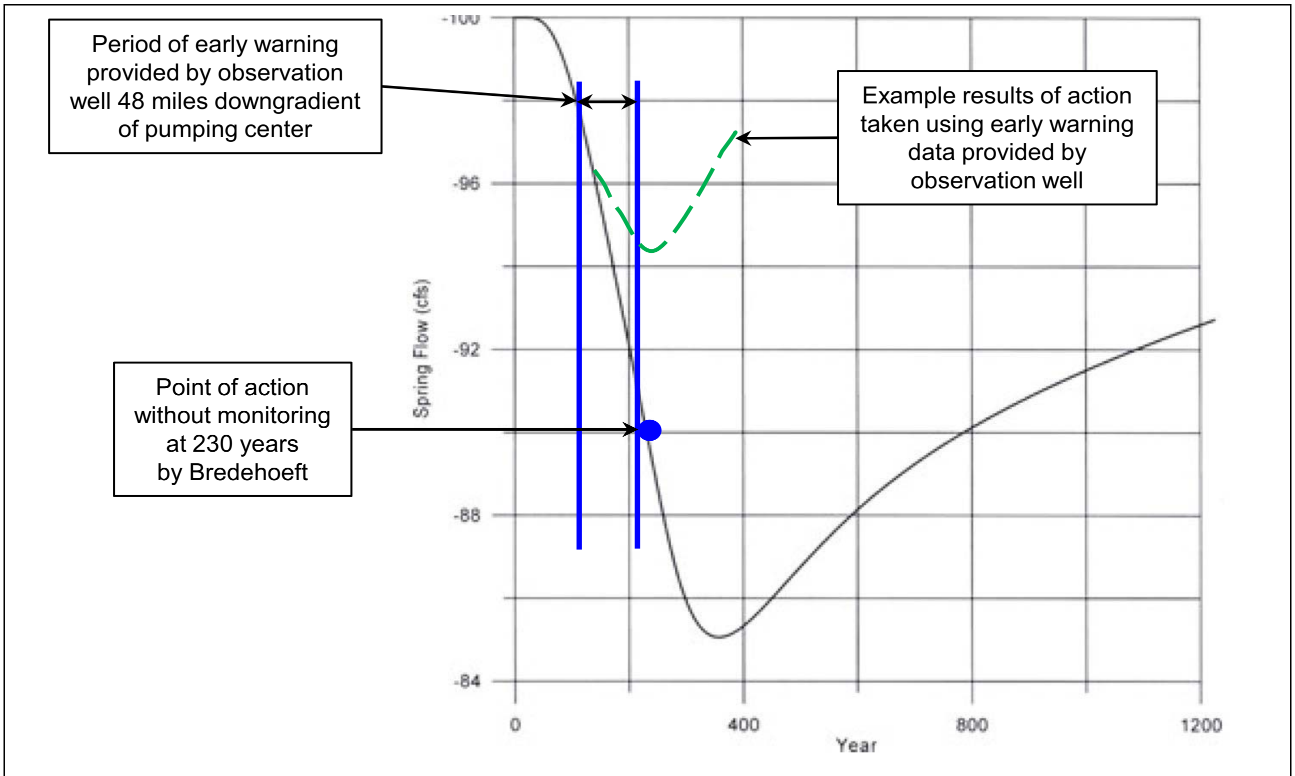


Figure 4. Plot of spring flow for pumping 100 cfs, 50 miles from the spring. Pumping was stopped after 230 years.

Source: Modified from Bredehoeft (2011b), Note: Text boxes and blue ranges added to original figure.

Figure 14
Effectiveness of Early Warning Monitor Well

The spring flow recovery presented in the Bredehoeft example is related to the model design and location of the recharge area, pumping center and spring. The actual recovery rate and duration of a particular well or spring is dependent upon site hydrogeologic conditions; variation in aquifer properties, pumping location, rate, and duration; production zone in the aquifer, recharge rates and source locations, degree of interception of spring source water, and boundary conditions. The readers of Bredehoeft (2011b) and Bredehoeft and Durbin (2008) should use caution in applying the projected recovery times and rates derived from the hypothetical example to real world projects. Hydrogeologic conditions associated with a specific project which influence recovery duration and rate would be expected to differ from those presented in the theoretical example presented in the Bredehoeft's expert report and articles.

In actuality, compared to the Bredehoeft (2011b) and Bredehoeft and Durbin (2008) examples, the Project Basins have a groundwater monitoring network in place. Pumping will not be continuous and may not be within the capture zone of a particular spring. The hydrogeologic conditions are more varied than in the example. The source aquifer of the pumping center may not be hydrologically connected with a particular spring of interest. Recharge sources and locations are more varied than the example in the articles indicate, especially in Spring Valley. As a result, the theoretical example and conclusions of Bredehoeft (2011a and b) and Bredehoeft and Durbin (2008) are oversimplified and flawed in regard to practical application to real-world conditions and the monitoring program established in the Project Basins. Monitoring would be effective in differentiating significant drawdown effects associated with pumping from natural variability over time. The use of monitor wells to provide early warning of significant drawdown is standard industry practice and will be effective.

3.0 Conclusions

The unsubstantiated statements and conclusions of Bredehoeft (2011a) are oversimplified and do not reflect the local hydrogeologic conditions, basic principles of managing water production well fields and state of the industry practice in regard to groundwater monitoring and adaptive management. Bredehoeft's expert report and articles dismiss understanding of the specific local hydrogeologic conditions to locate and operate individual wells in an optimal manner to minimize and manage impacts. Bredehoeft's expert report and articles also dismiss state of the industry project monitoring and adaptive management practices which would be actively utilized to refine predictive tools and system operation activities.

The degree of impacts presented by Bredehoeft are generalized and over exaggerated. Bredehoeft does not consider the degree of hydraulic connection between the specific pumping areas and areas of interest (streams, springs, wells, and phreatophytes). Bredehoeft's expert report and articles inadequately examine the site-specific conditions, and misapply generalized hypothetical examples to the project conditions and operations. Bredehoeft (2011a) does not identify what constitutes significant harmful effects and discounts or dismisses the effectiveness of state of the industry management and mitigation measures without proper scientific consideration and examination. Therefore, it would be inappropriate for a decision maker to apply the results and conclusions of Bredehoeft's expert report and articles to SNWA's pumping in the Project Basins.

4.0 References

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