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To Whom It May Concern:

RE: Upper Gallatin Valley Water Supply Development
Gateway, Montana
Initial Approach And Feasibility Assessment For Aquifer Storage And Recovery.

This report describes a legal and physical approach for the development of a new public water system for the greater Gallatin Gateway area with a service area that may eventually serve as far north as the Belgrade city limits.

The proposed water system is located on the Gillam Farm (approximately two and one half miles north of Gallatin Gateway). This evaluation is based on extensive on-site hydrogeologic investigations and in collaboration with Steve Custer at Montana State University.

Please feel free to contact our office with comments and questions.

Sincerely:

HKM Engineering Inc.

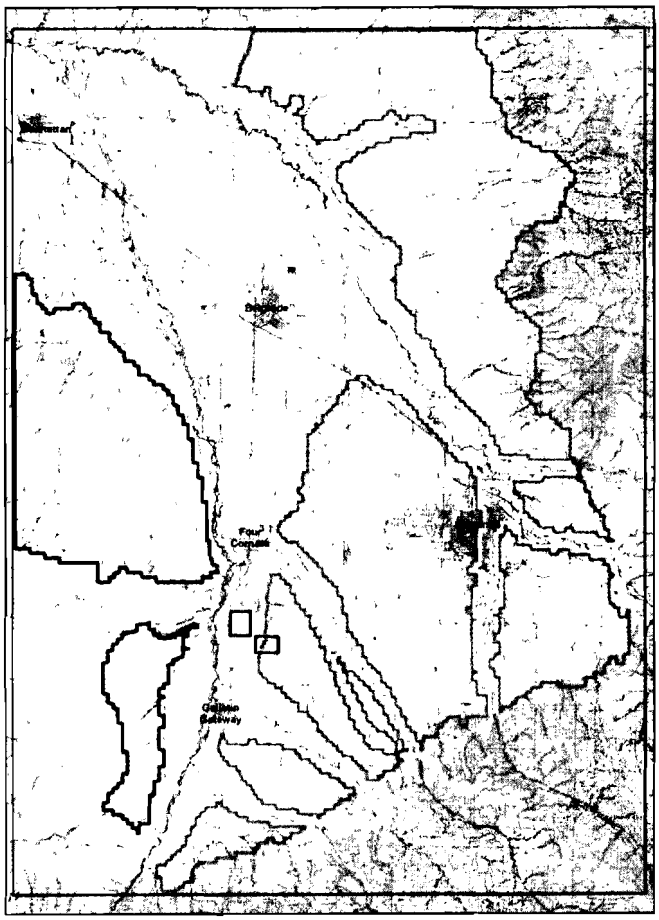
Jim Potts
Senior Hydrogeologist

ENVIRONMENTAL QUALITY COUNCI
September 11, 2006
Exhibit 15

PACIFIC WATER GROUP

UPPER GALLATIN VALLEY WATER SUPPLY DEVELOPMENT GATEWAY, MONTANA

INITIAL APPROACH AND FEASIBILITY ASSESSMENT OF AQUIFER STORAGE AND RECOVERY (ASR)



SEPTEMBER 8, 2006

HKM ENGINEERING

UPPER GALLATIN VALLEY WATER SUPPLY DEVELOPMENT

GATEWAY, MONTANA

INITIAL APPROACH AND FEASIBILITY ASSESSMENT OF AQUIFER STORAGE AND RECOVERY (ASR)

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SIGNATURE

This report, and Pacific Groundwater Group's work contributing to this report, were reviewed by the undersigned and approved for release.

Linton Wildrick

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1.0 EXECUTIVE SUMMARY

Development of land in the Gallatin Valley is complicated by the fact that many of the existing water rights are for surface water and are available only in the summer. Domestic use requires water year round. In order to convert the use, two problems must be overcome: legally making the water available through water right changes and physically making the water available through storage.

Considerations of recent water right decisions by the State Supreme Court and discussions with Montana's Department of Natural Resources and Conservation (DNRC) together indicate that it may be possible to develop a groundwater supply in the upper Gallatin Valley using a combination of water-right change applications for existing surface-water rights. Change applications would be filed to add groundwater sources (wells) as secondary points of withdrawal to the surface water rights and to change the purpose of use from irrigation to domestic and commercial uses. A portion of the annual quantity would be maintained for domestic irrigation and parks.

At least two issues resulting from previous approaches (Zoot Enterprises and Utility Solutions) remain unsettled – the statutory viability of augmentation and the definition of a municipal water supplier. The approach presented here does not depend on resolution of either issue, because it does not include conversion of the existing water rights to municipal uses, nor does it include application for new rights that would require mitigation. The recommended approach includes:

- changing a small portion of the irrigation water rights to year-around, in-house domestic and commercial uses,
- maintaining the remainder of the water rights for irrigation purposes, and
- adding wells as secondary diversion points for stored surface water.

The feasibility of this approach depends on physically storing the water during the summer months, and subsequently pumping the water down gradient during the rest of the year. This approach is called aquifer storage and recovery (ASR) methods. A complicating factor is the need to avoid the reduction of groundwater discharge to nearby rivers and canals.

A preliminary two-dimensional numerical model of the groundwater flow system was used to simulate a combination of subsurface injection or infiltration of surface water from Farmers Canal during a typical six-month irrigation season, together with year-around recovery from one or more wells located downgradient (northwest) of the injection or infiltration. To represent a worst-case scenario, the model was set up to withdraw the same amount of water as was injected or infiltrated on an annual basis. The hypothetical pumping schedule assumed that 80% of the annual quantity would be pumped at a constant rate during the irrigation season (May - October), and then 20% of the annual quantity would be pumped at a constant rate during the winter months (November - April).

The initial model simulations for this worst-case scenario indicated that streamflow would be reduced by a small amount in the West Gallatin River and Elk Grove Ditch at the end of October, the end of the lowflow season. At the end of April, the initial simulation indicated that streamflow would be reduced a small amount in Elk Grove Ditch, but that the West Gallatin River would gain flow. For a scenario in which the annual quantity pumped is reduced to slightly less than the annual quantity injected or infiltrated, the model is expected to indicate that depletion of flows in the West Gallatin River and Elk Grove Ditch can be eliminated.

The modeling results for Elk Grove Ditch are less certain than for the nearby reaches of the Gallatin River. This uncertainly will be reduced by incorporating the results of current field investigations into the model.

Additional modeling to find optimal locations and monthly rates for injection or infiltration and

pumping, as well as an optimal pumping rate, will be necessary after the results of current field investigations have been analyzed to develop improved input parameters for the model.

2.0 INTRODUCTION

This report describes our recommended permitting and feasibility modeling approach for development of a groundwater supply at a site that is typical of the upper Gallatin Valley, with respect to its historic water use for irrigation with canal water and its potential for conversion to groundwater development to supply domestic and commercial water uses. The report also describes the results of a reconnaissance-level groundwater model that was developed to assess the use of aquifer storage and recovery (ASR) to mitigate potential streamflow depletion by wells. Investigations have focused on the former Gillam farm, located between near Gateway. The proposed approach may be adaptable for application to a regional scale facility that would be capable of servicing other sites in the Gallatin Valley, between Gateway and Belgrade.

This report was prepared as part of Pacific Groundwater Group's (PGG's) consulting services subcontract with HKM Engineering, Inc., Bozeman, Montana. Under the project scope of work, this report fulfills the report deliverable for Phase 1. The work included initial feasibility modeling, a task that was anticipated to be part of the Phase 2 scope, but was verbally authorized to occur earlier in the project.

In preparation of this assessment, we have reviewed relevant documentation, including hydrogeologic reports for the site, hydrogeologic and engineering reports for similar nearby projects, previous DNRC decisions for nearby projects, and Montana water-law guidance reports. Also, we visited the Gillam site and met with HKM staff, attorney Michael Cusic, Dr. Custer and his students from Montana State University, and DNRC staff.

Our work was performed, and this report prepared, using generally accepted hydrogeologic practices used at this time and in this vicinity, for exclusive application to the Gillam properties near Four Corners, Montana, and for the exclusive use by HKM Engineering, Inc. and John Dunlap. This is in lieu of other warranties, express or implied.

3.0 PROJECT UNDERSTANDING

We understand that HKM Engineering wishes to explore methods for the development of a groundwater supply that maximizes the use of surface-water rights in the upper Gallatin Valley, for potential housing and commercial development at a particular site and at potential future sites in the area between Gateway and Belgrade. The project approach would develop not only a physical and legal source of water for the Gillam property, but would serve as a method and means to provide water to the greater area between Gallatin Gateway and Belgrade. Additional areas might be served by expanding the system's physical capabilities and combining additional early priority surface-water rights (outright purchases or use agreements) to satisfy future mitigation needs.

Current regulations imply that any new development must have no adverse hydrologic effects on river and creeks. Obtaining groundwater rights through conjunctive use of surface water and groundwater (seasonally varying surface-water storage and recovery at separate locations) is considered the best method of satisfying these criteria.

After preparation of necessary technical analyses and documents for the site, applications to modify the existing surface-water rights would be made to the Montana Dept. of Natural Resources Conservation (DNRC).

4.0 WATER RIGHTS

Several aspects of Montana water laws and regulations, particularly the Upper Missouri River Basin Closure, have bearing on the available options for groundwater supply development at the Gillam site.

4.1 UPPER MISSOURI RIVER BASIN CLOSURE

The Upper Missouri River Basin is closed to new appropriations by statute, with exceptions for certain types of permit applications. Montana Code Title 85-2-343 states that the exemptions include:

- applications to appropriate groundwater
- applications to appropriate water for non-consumptive use
- applications to appropriate water for domestic, municipal, or stock use
- applications to store water during high spring flows.

An application to appropriate groundwater must demonstrate that there would be no "immediate and direct connection" to surface water. HKM Engineering has concluded (and we concur) that groundwater at the Gillam site is hydraulically connected to the West Gallatin River, and probably to Elk Grove Ditch, downstream of the Gillam property, so this exception would not be of use to the Gillam project. Furthermore, this exemption has been interpreted by the State Supreme Court to include the "pre-capture of tributary ground water" without regard to the timing of the effect. For all practical purposes, the ruling effectively nullifies the groundwater exemption, because for typical hydrogeologic conditions in the Gallatin River Basin, it would be hard to demonstrate that pre-stream capture would never occur following a groundwater withdrawal. Only very deep and ancient groundwater might qualify for the exemption, but such water would likely have a high dissolved mineral content and probably would be "mined" at even very low pumping rates, because little or no recharge would occur.

Non-consumptive uses include diversions that return the water to the same source, such as a fish hatchery along a river, or a heat pump system that recycles the water back to the aquifer from which it came. None of the future uses at a site such as the Gillam property are currently anticipated to be non-consumptive. In a regional scheme, wastewater could be returned to the aquifer by positioning collection systems, treatment plants, and injection wells or basins at strategic locations in other parts of the valley. These locations would be positioned strategically to offset and mitigate the effects of groundwater withdrawals.

The domestic exemption ordinarily applies to single-family homes and has not been tested for larger residential projects such as the Gillam site.

The municipal exemption is generally applied to governments and sewer districts. Utility Solutions attempt to adopt the municipal exemption is still pending. However, this approach has been met with extreme opposition by objectors due to a private utility attempting municipal status. Until the definition of municipal is clarified by DNRC, the Gillam project is unlikely to be considered a municipality, and so this approach is not useful for the time being.

The exemption for storing water during high spring flows would not be useful on a regular basis. DNRC's Water Availability Study of the Upper Missouri River Basin, (Dec. 1997) concluded that PPL Montana's and USBR's water rights for hydropower limit the availability of unappropriated water for new consumptive uses. Therefore, new water rights to divert part of higher streamflows from the Gallatin during the snowmelt period would be available only during April through July and only during two out of ten years.

4.2 MITIGATION FOR WATER RIGHT CHANGES

We agree with previous recommendations (Cusick, 2005; HKM staff communications) that the best option for obtaining a groundwater permit for a site in the upper Gallatin Valley is through a change application for use of surface water to recharge groundwater when water is available in the Farmer's Canal (likely May 15th through the end of September). The rights would be preserved as surface-water right, but with wells designated as secondary points of withdrawal for the stored surface water. Domestic and parks irrigation would occur under the existing purpose of use. Indoor domestic or commercial water use would occur year-round using the surface water stored underground or impounded during the previous irrigation season. The water permit criteria (Montana Code Title 85-2-311 and 85-2-343) would be satisfied by this approach, including that:

- the period of use (in effect, the diversion of water to the property) would not change from that of the historic irrigation practice at the property,
- most of the injected or infiltrated water would remain under the water-right owner's control for later withdrawal from wells,
- the historic rate of return flow would not be reduced,
- the new use of water will not become more consumptive than previous irrigation uses, and
- pre-stream capture of tributary groundwater would be fully mitigated.

4.3 TECHNICAL APPROACH TO WATER-RIGHT OPTIONS

The water-right change application(s) for the Gillam development will involve the artificial subsurface storage and subsequent recovery of surface water. Such an approach is referred to in the groundwater industry as *artificial storage and recovery*, or *ASR*. This approach would be designed to ensure that surface-water flows (in rivers, streams, irrigation ditches) are not reduced, either by:

- loss from the stream via the process of induced infiltration of surface water into the ground; that is, capture of water that was flowing in the steam, or
- reduction of groundwater discharge to surface waters (called baseflow) via the process of pre-stream capture.

Surface waters of local concern are the West Gallatin River, lower South Cottonwood Creek, and Elk Grove Ditch. Aquatic habitat and downstream water rights are the main concern for the River and Creek, while downstream water rights are the main concern for the Ditch.

4.4 ASR APPROACH

Typical methods used in ASR projects include pressurized injection into screened wells, passive infiltration through drain fields (buried perforated pipes), or passive infiltration beneath open unlined ponds. Analysis of the preferred means of ASR is not presented at this preliminary stage of the project and would need further on-site investigation and testing. With further development of the groundwater model described later in this report, PGG will support HKM Engineering in the analysis of such alternatives, as required.

General attributes of a potential ASR approach at the Gillam site are as follows:

- A groundwater supply would be pumped from wells completed either in the unconfined Quaternary alluvial aquifer or in the confined Tertiary aquifer. Although withdrawals from the Tertiary aquifer might minimize streamflow capture, it would be less advantageous due to lower yields and water quality, as compared to the Quaternary aquifer.
- Groundwater at the Gillam site would be augmented by surface-water injection or infiltration from the Farmers Canal to

the extent of the appurtenant water rights, which has been tentatively estimated at approximately 390 af/yr (Saunders and Waples, 2006).

- Injection or infiltration would occur only during the historic irrigation season, when legally available surface water is present in the Farmers Canal. Water would most likely be available in the Farmers Canal from May through October, or 6 months duration. (This is less than the period specified in the Gillam water rights, which is April through November, or 8 months duration.)
- An alternative to extend the period of injection or infiltration would be the construction of a lined reservoir on the upper portion of the Gillam farm to store water beyond the end of the irrigation season. The injection or infiltration rate during the irrigation season accordingly would be reduced, so that the combined rate of injection or infiltration plus surface reservoir storage would not exceed the historic rate of consumption.
- Throughout the year, groundwater withdrawals would be balanced by prior storage (injection or infiltration) of surface water. Withdrawals could be higher during the late spring and summer and lower during the fall and winter to meet typical domestic or commercial water demands. During the irrigation season, the groundwater withdrawal rate would remain less than the injection or infiltration rate, so that some of the stored water would continue to be available for withdrawal throughout the winter.
- At this site, injection or infiltration might cause flooding of adjacent low-lying properties, particularly in the upper reach of Elk Grove Slough. This could more likely be avoided by injecting the surface water upgradient (with respect to groundwater flow) from the recovery wells, in this case in the southeastern part of the farm. This part of the farm also is farther from the upper Elk Grove Ditch and where the water table is deeper than in the northwestern parcel.
- Although the injection or infiltration of reclaimed wastewater at the site would greatly extend the value of the surface-water rights, this option was not included in the current analysis for the Gillam site, because it limits the scaling of the project by requiring commitment to a location of the treatment facility early in the project. Injection or infiltration of reclaimed wastewater farther down-valley (northward) could be of value to other developments in that area.

The ultimate success of this ASR approach depends on DNRC's acceptance of the scientific analysis regarding surface-water effects, as well as Montana water code considerations. We believe that a water-budget neutral ASR approach is feasible, as explained in Section 5 of this report.

4.5 POTENTIAL OBJECTIONS BY AGENCIES OR NON-GOVERNMENTAL ORGANIZATIONS

Various objector groups, including Montana Fish and Wildlife, irrigation districts, and non-government organizations (NGOs), such as the Western Rivers Network, have challenged water-right applications in the Gallatin Valley in recent years. These challenges often used state-of-the-art scientific arguments and have been successful in stopping several projects. The principal scientific objection to new groundwater developments has been that streamflow would eventually be depleted by wells. Mitigation for the pre-stream capture effects was not offered for several projects, resulting in denial of their water-right applications. In the case of the combined project by Utility Solutions and Zoot Enterprises, mitigation of pre-stream capture by infiltration of surface water was offered and eventually accepted by DNRC and objectors.

At least two issues resulting from these challenges remain unsettled – the statutory viability

of augmentation and the definition of a municipal water supplier. The water rights approach recommended for the upper Gallatin Valley does not depend on resolution of either issue, because it does not include conversion of the existing water rights to municipal uses, nor does it include application for new rights.

As described above, the ASR approach includes:

- changing a small portion of the irrigation water rights to year-around, in-house domestic and commercial uses,
- maintaining the remainder of the water rights for irrigation purposes, and
- adding wells as secondary diversion points for stored surface water.

The diversion of the irrigation rights would occur when surface water is stored underground, and the beneficial use would occur when it is recovered and used for domestic, commercial, and irrigation purposes. Any portion of the injected or infiltrated water that is not recovered by the wells would discharge to streams and enhance baseflows. Withdrawals would not exceed the amount stored and would not result in net streamflow capture on a reach-by-reach basis.

5.0 HYDROLOGIC SYSTEM MODELING FOR ASR FEASIBILITY

Given the complexity of the groundwater flow system around the Gillam site, it is appropriate to use a numerical groundwater model to assess the effects of an ASR approach. A numerical model can incorporate complex arrangements of hydrologic boundaries (for example, streams and impermeable rocks), hydraulic properties of subsurface materials, arrangements of wells, and varying rates of injection or infiltration. A numerical model can be relatively easily modified to add more components and as many aquifers and aquitards as desired.

For the reconnaissance assessment of the feasibility of ASR at the Gillam site, we created a large-scale, but conceptually simple, representation of the groundwater flow system in the uppermost aquifer, both in the Gallatin Valley and surrounding uplands. This is a larger-scale, more comprehensive implementation of the modeling approach used by Utility Solutions for testing the feasibility of their mitigation approach for the Four Corners area.

5.1 HYDROGEOLOGIC SETTING

The following summary of hydrogeologic conditions in the Gallatin Valley is based on information provided in Hackett, and others (1960), Slagle (1995), Vuke, Lonn, Bergg, and Kellogg (2002), Lonn and English (2002), and Vuke (2003).

The Gallatin Valley encompasses an area of about 540 square miles and is characterized by a deep structural basin filled with up to 6000-ft of Tertiary and Quaternary aged sediments (Figure 1). The lowermost portions of the valley fill consist of fine-grained Tertiary sediments, mainly of lacustrine (lake) origin. These in turn are overlain by coarse-grained Quaternary alluvium, consisting predominantly of cobbles and gravel, intermixed with varying proportions of sand, silt, and clay.

In the Camp Creek Hills area west of the West Gallatin River, fine-grained Tertiary sediments cover the surface. East of the river, coalescing Tertiary to Quaternary age alluvial fans form the Bozeman Fan, an upland consisting of a mixture of coarse and fine-grained sediments at the surface. Bedrock underlying the valley-fill and uplands and exposed in the surrounding area consists of metamorphic, sedimentary, and volcanic rocks.

The Quaternary alluvium is generally the most permeable material in the study area with transmissivity values at least an order of magnitude greater than the surrounding and underlying Tertiary sediments. Because of its higher permeability, most of the groundwater flow in the area

probably occurs within the Quaternary alluvium, with a lesser flow within the uppermost Tertiary sediments, deeper Tertiary sediments, and bedrock units. Well yields from the Quaternary Alluvium are correspondingly higher than from the other units. The Quaternary alluvium contains the primary source aquifer for irrigation and domestic water supplies, while the typically lower yields from the Tertiary sediments are not sufficient for agricultural irrigation.

The conceptual model of the Gallatin Valley groundwater flow system focuses on horizontal flow within the alluvial Quaternary and Tertiary aquifers and discharge to surrounding streams. Groundwater flows generally toward the nearest river or stream, with a strong northerly regional trend of flow corresponding to the topography. Because of their relatively lower permeability, the Tertiary sediments beneath the Quaternary aquifer were not considered to be significant for this initial assessment and were not represented in the model.

5.2 GROUNDWATER FLOW-SYSTEM MODELING APPROACH

A numerical model of the groundwater flow system was developed using the *MODFLOW 2000* program (Harbaugh et. al, 2000) and the commercially available graphical user interface *Groundwater Vistas*™ by Environmental Simulations, Inc. The numerical model simulates the groundwater flow system with a series of mathematical equations that describe the physical processes occurring in the system. The solution to a groundwater flow model is the spatial and temporal distribution groundwater elevations (heads). From the groundwater head solution, the model calculates groundwater fluxes to and from rivers or wells.

A two-dimensional groundwater flow model was developed to conduct a preliminary assessment of the ASR approach for mitigating streamflow capture due to groundwater withdrawals at the Gillam site. The model represents the groundwater flow system of the uppermost aquifer in the Gallatin Valley and surrounding foothills. Information on groundwater elevations (heads), aquifer hydraulic properties, ground-surface elevations, and elevations of streambeds and canal beds were used as input to the model.

The model domain extends northward from where the West Gallatin River emerges from the mountains, a few miles upstream from Gallatin Gateway, to beyond the confluence of the West and East Gallatin Rivers (**Figure 2**). The regional geographic extent (domain) of the model represents all the stream reaches that might be affected by pre-stream capture due to wells at the Gillam site.

Although most of the pre-stream capture would occur within a few miles of the ASR site, a small portion would occur farther downstream over a longer period. This is simply a function of conservation of mass. This modeling approach is intended to account for the total water budget and all possible streamflow effects, as well as to demonstrate that there are no unanticipated hydrologic effects due to groundwater development at the site. This also would satisfy one of the main objectives of the ASR effects modeling, which is to estimate how to completely mitigate for the pre-stream capture effects.

The broad domain of the model also will be useful for modeling the effects of additional developments north of the Gillam site. With appropriate updates, the model will be capable of simulating ARS anywhere in the Gallatin Valley, with less effort than would be needed to develop a new groundwater model for each site. We expect that the model can easily be modified to incorporate new information as it becomes available.

Further enhancements to the model are needed to more accurately simulate the local effects of ASR, but were not part of this initial reconnaissance effort. For the enhancement, we would use a technique called "local grid refinement", a capability of the MODFLOW 2005 program that allows one to imbed a finer grid (more detail) within the larger regional model, When the local model is simulated, the regional model need not

be run, but provides important information to the local model. This grid-refinement technique can then be used anywhere within the larger model for additional sites in the Gallatin Valley.

The modeling approach for the Gillam site uses the *superposition principle*, wherein "stresses" are superimposed on the existing flow system. Surface water storage (injection or infiltration) and recovery for ASR are the superimposed stresses, in this case. Although an estimate of natural recharge from precipitation was included in the model for preliminary testing purposes, one does not need to know this rate in order to perform the superposition analysis. Also, the model relies on existing values of aquifer and streambed hydraulic properties that were developed from on-site testing by HKM Engineering or published values. By assuming these values to be representative, the modeling effort did not require calibration to field data. The superposition principle was used in the numerical model by Nicklin Earth and Water for Utilities Solutions and was acceptable to both DNRC and the objectors groups. One of the groundwater experts for the objectors, John Bredehoeft, is a widely respected hydrogeologist and leading proponent of using the supposition method in assessing streamflow capture (Bredehoeft, 2006).

The Quaternary aquifer is unconfined, but may be approximated as confined (a simpler approach). This is justified because the aquifer's saturated thickness is not expected to change significantly (less than 5 %) under the imposed storage and recovery stresses for the model simulations.

The results of the model simulations described in this report should be viewed as an approximate, first-cut appraisal of the ASR feasibility. Assessing the approximate relative capture effects among the larger and closest streams was our main objective. The simulated effects of the ASR stresses on local conditions, such as the flow in Elk Grove Ditch, or the shallow groundwater levels on nearby surrounding properties, are less certain, because there are uncertainties in our current hydrogeologic understanding. We did not "optimize" the relative rates or locations of storage and recovery. The optimal rate of groundwater withdrawal could be more than 10% less than the injection or infiltration rate that we used in the model. We anticipate that the results of in-progress field studies by HKM Engineering and Dr, Steven Custer of MSU will provide improved accuracy of the model at the local scale.

5.3 MODEL EXTENT

A single-layer numerical model of the groundwater flow system was constructed to simulate horizontal groundwater flow in the interconnected Quaternary alluvium in the valleys and shallow Tertiary sediments of the benches and foothills (**Figure 2**). The model domain incorporates the West and East Gallatin Rivers, from their upper reaches where bedrock outcrops to their confluence near the City of Manhattan. The Quaternary and Tertiary aquifer boundaries were delineated from published geologic maps (Vuke et al, 2002; Lonn and English, 2002; and Vuke, 2003). All bedrock units within the model domain are considered to be no-flow boundaries.

The model grid (**Figure 2**) consists of 248 rows and 230 columns, with an equal cell spacing of 800 feet square over most of the model domain, but decreasing to 100 feet around the Gillam site. The total area covered by the grid is 540 square miles, with 57,040 model cells. Large areas to the south and east were set as inactive cells where bedrock is present. The active part of the model domain represents 82% of the model grid.

A uniform layer thickness of 1,800 feet was assigned to the single-layer model in order to accommodate the total vertical relief in riverbed elevations within the model domain.

5.4 MODEL PARAMETERS

Parameter values used in the model are summarized in **Tables 1 and 2**.

Constant transmissivity and storativity values were assigned to each aquifer zone in the model (**Table 1**). The transmissivity assigned to the Quaternary alluvial aquifer was calculated from a recent aquifer test performed at the northwestern Gillam parcel (HKM Engineering, 2005). The test was conducted with a pumping well and multiple observation wells. The storage coefficient also was calculated from the pumping test data and was assumed to be constant throughout the model domain; the value is close to that used in Nicklin Earth and Water's (2005) model for Utility Solutions. Transmissivities for the Tertiary aquifer in the Bozeman Fan and Camp Creek Hills area were assigned the values used in the Nicklin Earth and Water model.

The West and East Gallatin Rivers and their main tributaries (**Figure 3**) are simulated with the MODFLOW River Package. The River Package simulates the flow of water between an aquifer and a stream. Water can flow from the aquifer to the stream (a gaining stream reach) or from the stream to the aquifer (a losing stream reach), depending whether stream stage or groundwater head is higher. Stream stage elevations in the model were approximated as constant and were estimated from 7.5-minute topographic maps. The rate of exchange depends partly on the permeability of the streambed sediments. The conductance parameter was estimated to have different values for the rivers and tributaries (**Table 2**). Soon to be completed research by MSU will provide a more representative value for the West Gallatin River and Elk Grove Ditch near the Gillam site.

5.5 MODEL SIMULATIONS

Three types of model simulations were performed for assessing streamflow capture and mitigation by ASR (**Table 3**):

- First, a steady-state simulation was used to evaluate groundwater fluxes to streams ("stream fluxes") under pre-withdrawal and pre-storage-and-recovery conditions, referred to hereafter as the "base-case" condition.
- Second, a transient withdrawal simulation was used for evaluating changes to the base-case stream fluxes, in response to pumping groundwater from a well at the Gillam site.
- Third, a transient, simultaneous storage and recovery simulation (ASR condition) was used to evaluate whether changes to the base-case stream fluxes caused by the withdrawal can be mitigated with groundwater injection or infiltration at the site (see injection and recovery locations in **Figures 2, 3, and 4**).

A steady-state type of simulation calculates groundwater heads and fluxes that represent long-term *time-averaged* conditions, based only on the estimated transmissivity (permeability multiplied by unit thickness) of portions of the hydrogeologic unit and hydraulic inputs (such as injection or infiltration) and outputs (such as pumping wells).

Transient simulations are used to analyze *time-dependent* conditions, such as variable pumping or injection or infiltration rates, and result in a set of calculation solutions for predefined time steps. In addition to what is needed for steady-states simulations, transient simulations require an initial estimate of groundwater heads (in this case, from the steady-state solution), aquifer storage characteristics (storativity), and transient stresses. With transient simulations, monthly (or any duration) changes in groundwater elevations and fluxes can be evaluated. Transient simulations were run with monthly stress periods for a period of 50 years, in order to reach an approximate "cyclic steady-state condition". Comparison between calculated heads for successive annual periods verified that only very small changes occurred from year to year, as would be expected for steady-state conditions.

Storage recovery at the Gillam farm was simulated with wells screened in the Quaternary aquifer. The wells were assumed to fully penetrate the aquifer. No other wells are simulated in the model. Groundwater storage and recovery rates for the transient simulations were based on the tentatively estimated total Gillam water rights of 390 af/yr.

To obtain the worst-case response, annual groundwater withdrawals were simulated as being equal to the annual amount of surface-water injected or infiltrated (390 af/yr). Groundwater withdrawals were assumed to occur throughout the year, from a single well, with 80% of the annual amount (390 af/yr) occurring at a constant rate from May through October and 20% at a constant rate from November through April. Simulated mitigation of withdrawals involved surface-water injection or infiltration into the aquifer at a single location, during May through October. The simulated location of the simulated injection or infiltration and recovery wells are shown in **Figures 2, 3** and **4**, and the monthly volumes of water are summarized in **Table 3**.

For all three simulations, fluxes to and from streams were evaluated for defined stream reaches consisting of contiguous model river cells (**Figure 3**).

5.6 RESULTS OF STREAMFLOW CAPTURE SIMULATIONS

The model simulation results for streamflow capture are shown in **Table 4.** Model calculated net gains or losses (in cfs) of streamflow for the end of April and end of October for each reach in **Figure 3** are shown in columns 4 and 6 ("Capture per Reach") of **Table 4**. The calculated progressive downstream capture rates for each stream are shown in columns 5 and 7. Note that the capture for tributaries is added to the stream into which it flows. For example, the progressive capture or gain for South Cottonwood Creek is added to that in the West Gallatin River, Elk Grove Ditch capture or gain is added to that in Hyalite Creek, and so on.

The model calculated that at the end of October, the West Gallatin River and Elk Grove Ditch would experience a small net decrease in baseflow. The maximum streamflow decrease would be 0.015 cfs (or 6.7 gpm) in the West Gallatin and 0.038 cfs (or 17 gpm) in Elk Grove Ditch (column 5, **Table 4**). In comparison, the simulated pumping rate for May to October was 0.86 cfs (or 386 gpm) and the injection rate was 1.08 cfs (or 482 gpm). Therefore, the streamflow decrease is a small percentage of the project volume. Note that South Cottonwood Creek and the upper Gallatin River would experience a flow increase at all times. By the end of April, only Elk Grove Ditch would experience a small net decrease of 0.012 cfs, or 5.4 gpm (column 7, **Table 4**). As mentioned above, this is a worst-case scenario, and some net streamflow capture is expected when the storage and recovery amounts are equal on an annual basis. At a lower rate of withdrawal, there would be no net depletion of streamflow in any reach.

Because characterization of local conditions around the Gillam site have not been completed (HKM and MSU investigations are underway), uncertainty remains regarding the accuracy of the modeled ditch capture effect. When the findings of current investigations can be incorporated into the model, the simulation should become more accurate and the modeling results may change.

In general, the results of the model simulations indicate that an ASR approach would be successful, because a large percentage – but not all - of the injected or infiltrated water can be recovered without depleting streamflow. Optimization of the relative rate of withdrawal (recovery) will be conducted in subsequent modeling.

5.7 IMPAIRMENT OF NEARBY WELLS BY DRAWDOWN WHEN RECOVERY WELLS ARE PUMPED

Pumping a new well at the Gillam site would cause drawdown of groundwater levels in nearby water-supply wells, such as at the Elk Grove Development to the north. When the pumping is mitigated by injection or infiltration of surface water (recharge), The numerical model indicates that drawdown would be only a few feet at most and only a small part of the available drawdown in the uppermost aquifer (see **Figure 4**). The drawdown in adjacent properties, such as the Elk Grove Development, was estimated to be less than five feet. Given that the Quaternary aquifer has a saturated thickness of 90 feet or more near the Gillam site, the small amount of net drawdown would not impair the production from any nearby well.

Mounding (water-level rise) would occur around the injection or infiltration facility, in both the Quaternary and Tertiary aquifers. The mound in the Tertiary aquifer under the Bozeman Fan, east of the injection or infiltration location (**Figure 4**), is the remnant of the previous winter's injection or infiltration period. Mounding along Elk Grove Slough, above the Gillam site, could cause flooding of the field. This aspect will need to be tested further.

6.0 RECOMMENDATIONS FOR ADDITIONAL GROUNDWATER ANALYSIS AND MODELING

Additional work is needed to fully incorporate regional groundwater information into the two-dimensional numerical model, as well as the soon-to-be-released (late September 2006) findings of local research by Dr Custer at MSU. In the interest of providing a timely initial analysis, we have incorporated currently available, local (within a few miles) hydrologic information, particularly the results of testing at the Gillam site by HKM Engineering, and focused on the general regional behavior of the model. Future modifications and upgrades to the model are recommended for two reasons.

First, we should anticipate that the level of scrutiny of any future proposal could be greater than for the Utility Solutions model by Nicklin Earth and Water. Second, a more accurate model is needed to test the local effects of ASR options at the Gillam site, including potential flooding on nearby properties. Greater confidence in the model predictions will require, at a minimum, aquifer testing on the southeastern parcel, a seepage run in lower South Cottonwood Creek, and water-level measurements/elevation surveying of two or three wells along South Cottonwood Creek. Once additional information is incorporated into the model, it is expected to be suitable for optimizing the relative rates and locations of injection/infiltration and withdrawals.

The proposed model changes are not likely to change our initial finding that ASR is possible at the Gillam site, although the potential recovery rate will decrease to some extent. Changes in aquifer transmissivity and storativity parameter values in the model will cause capture to redistribute somewhat among the various stream reaches, but the stream-flow gains ("negative" capture) in the upper West Gallatin River and lower South Cottonwood Creek likely will continue to compensate for capture from downstream reaches.

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Table 1: Aquifer Hydraulic Properties.

Aquifer	Transmissivity (ft^2/dy)	Storativity
Quaternary Alluvium	10,000	0.2
Tertiary – Bozeman Fan	1,000	0.2
Tertiary - Camp Creek Hills	200	0.2

Table 2: River Conductance Parameters.

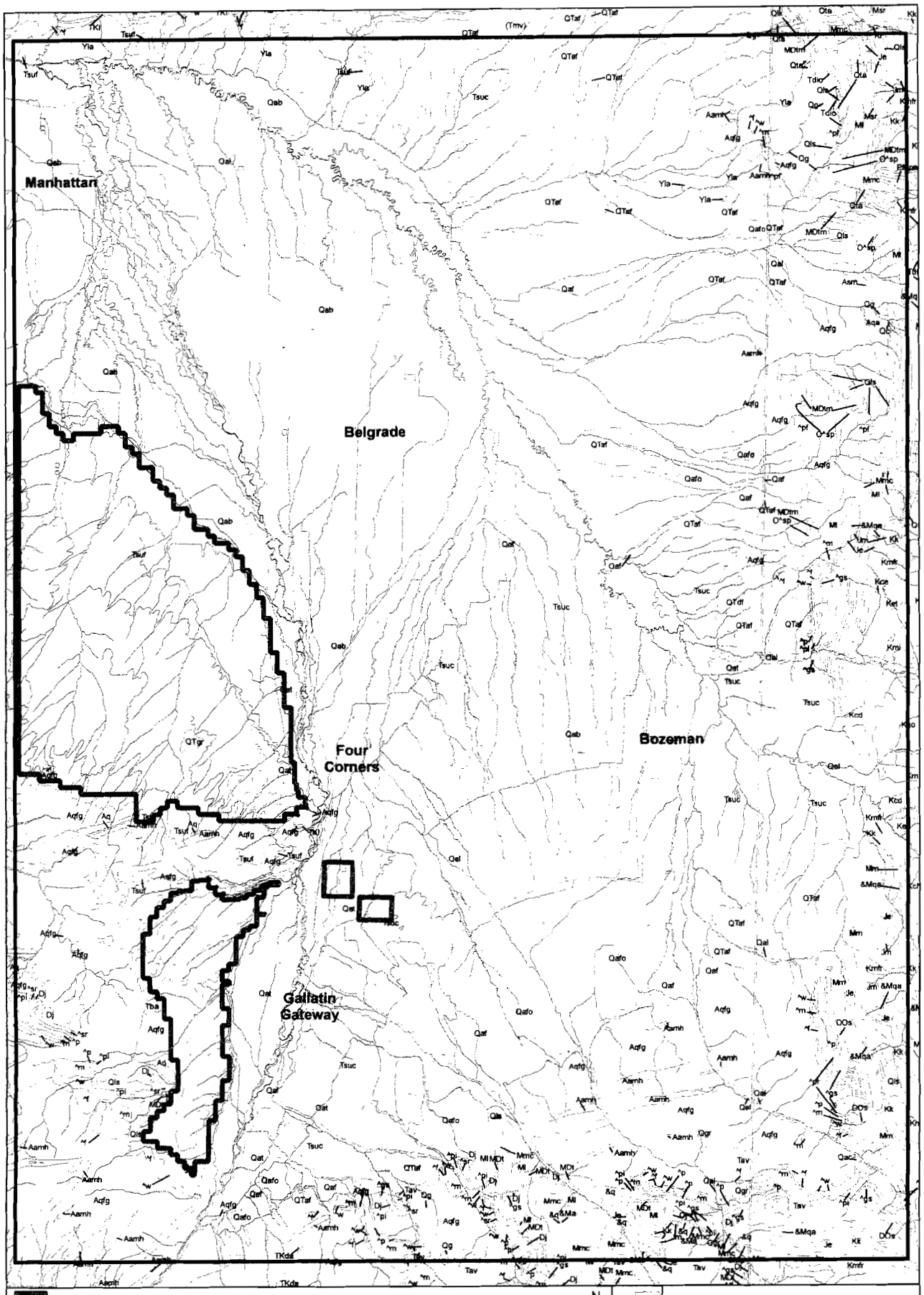
River	Kr (ft/d)	W (ft)	b (ft)
East Gallatin	25	100	5
West Gallatin	25	50	5
Tributaries	2	10	5

Table 3. Simulated Monthly Rates of Groundwater Withdrawal and Artificial Recharge.

Month	Withdrawal (ac-ft)	Injection (ac-ft)
May	52.85	66.07
June	51.15	63.93
July	52.85	66.07
August	52.85	66.07
September	51.15	63.93
October	52.85	66.07
November	12.86	0.0
December	13.29	0.0
January	13.29	0.0
February	12.00	0.0
March	13.29	0.0
April	12.86	0.0
Annual Sum	390.00	390.00

Table 4. Pre-Stream Capture of Tributary Groundwater

			End of October and Six-Month Injection Period		End of April	
Reach	Reach Name	Location	Capture per Reach (cfs)	Progressive Downstream Capture per Stream (cfs)	Capture per Reach (cfs)	Progressive Downstream Capture per Stream (cfs)
0	West Gallatin River	Above South Cotton Wood	0.009	0.009	0.010	0.010
1	West Gallatin River	Below South Cotton Wood / Upstream of Property	0.029	0.038	0.030	0.040
2	West Gallatin River	Next to Gillam Property	-0.046	-0.008	-0.008	0.032
3	West Gallatin River	Downstream of Property	-0.006	-0.015	-0.002	0.029
4	West Gallatin River	Further Downstream of Gillam Property	0.000	-0.015	0.000	0.029
5	West Gallatin River	Further Downstream of Gillam Property	0.000	-0.015	0.000	0.029
6	West Gallatin River	Further Downstream of Gillam Property	0.001	-0.015	0.001	0.029
7	West Gallatin River	Further Downstream of Gillam Property	0.000	-0.014	0.000	0.030
8	West Gallatin River	Further Downstream of Gillam Property	0.001	-0.013	0.002	0.031
9	S. Cotton Wood Cr.	Upper reach	0.000	0.000	0.000	0.000
10	S. Cotton Wood Cr.	Lower Reach	0.024	0.024	0.026	0.026
11	Hyalite Creek	Uppermost reach	0.002	0.002	0.002	0.002
12	Hyalite Creek	Below reach 11, abv confluence with Elk Grove Ditch	0.002	0.004	0.002	0.004
16	Hyalite Creek	Below 12 along Bozeman Fan Boundary	0.000	0.004	0.000	0.004
17	Hyalite Creek	Last reach before confluence with East Gallatin	0.000	0.005	0.000	0.005
13	Elk Grove Ditch	Above Property	0.017	0.017	0.009	0.009
14	Elk Grove Ditch	Within Property	-0.041	-0.024	-0.017	-0.008
15	Elk Grove Ditch	Below Property before confluence with Hyalite	-0.014	-0.038	-0.004	-0.012
18	East Gallatin River	Below Confluence with Bozeman Creek near Bozeman	0.001	0.001	0.001	0.001
19	East Gallatin River	Below Bozeman but before confluence with Hyalite	0.002	0.003	0.002	0.003
20	East Gallatin River	Just below confluece with Hyalite	0.003	0.006	0.003	0.006
21	East Gallatin River	Above Bozeman and Confluence with Bozeman Creek	0.001	0.007	0.001	0.007
22	Bozeman Creek	The whole creek	0.000	0.000	0.000	0.000
NEGATIVE NUMBER = Flow Captured From River Due to ASR						
POSTIVE NUMBER = Flow Contributed to River Due to ASR						



Gillam Properties

Model Domain

Model Transmissivity Zones

10,000 Feet^2/Day

1,000 Feet^2/Day

200 Feet^2/Day

See original source documents for geologic unit names and descriptions.

Surficial Geology Source:
Vance et al, 2002 MBMG 469 - Geologic Map of Bozeman 30'x60' Quadrangle
Berg, R.B., Lopez, D.A., 2000 - MBMG 406 - Geologic map of the Livingston 30' x 60'

N

0 Feet 10,000

Figure 1
Surficial Geology, Gillam Project Location, and Model Transmissivity Zones

P G

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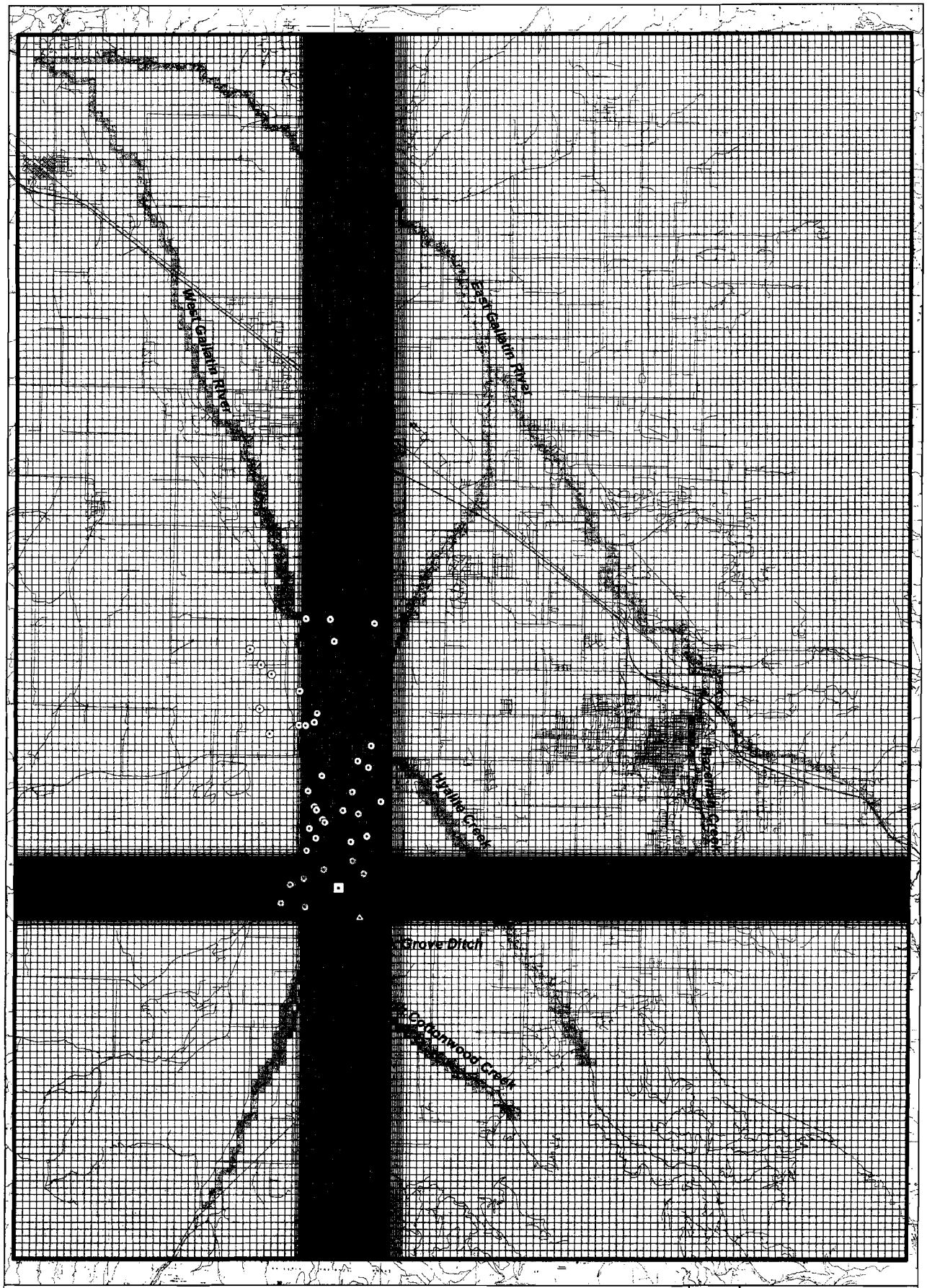

River Cells
Head Targets (Monitored GWIC Wells)
Injection Well
Water-supply Well
Gillam Properties
Model Domain
Active Flow Cells
No-flow Cells

N

0 Feet 10,000

Figure 2
Model
Grid & Cells

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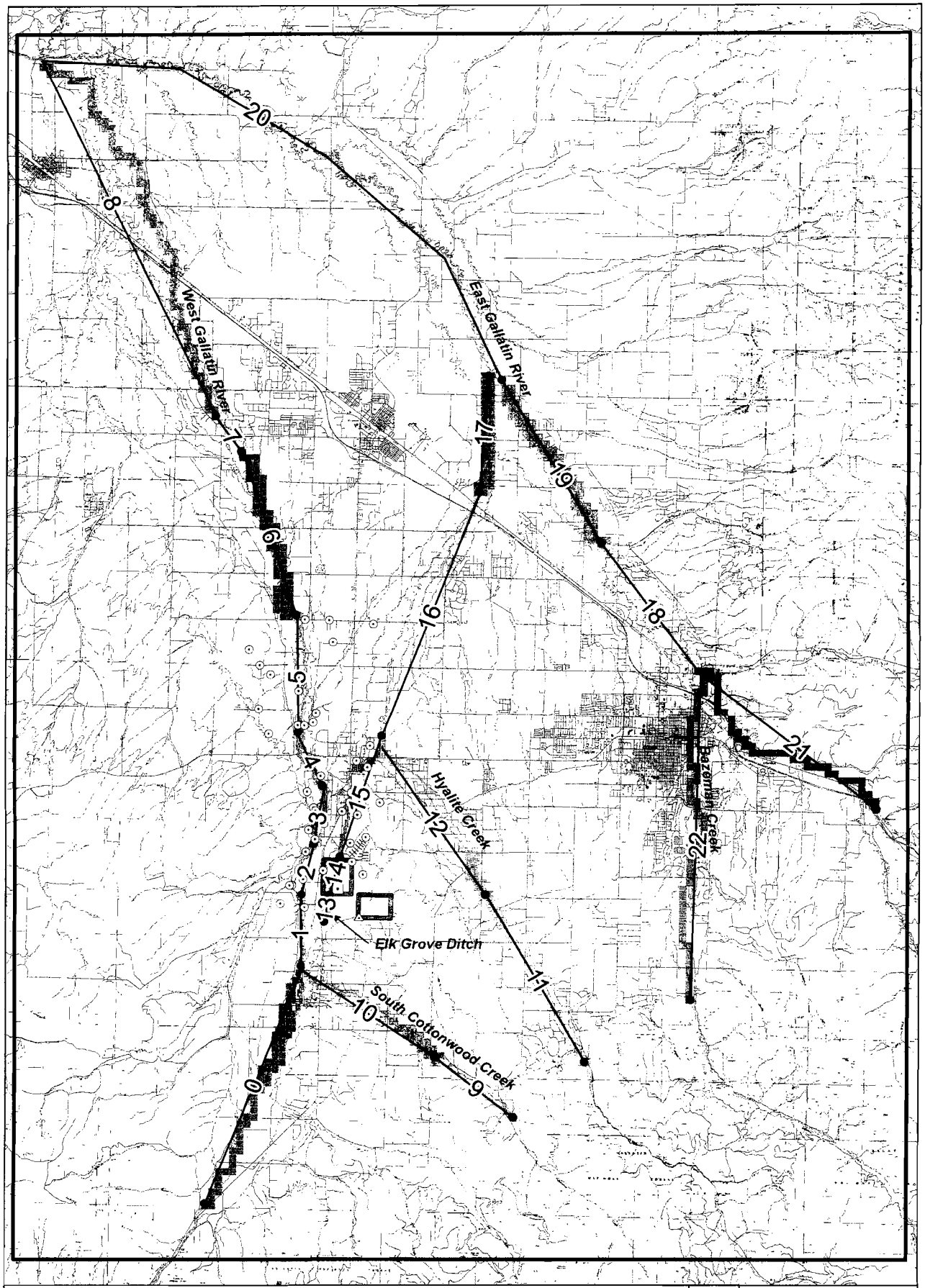

River Reaches
Head Targets (Monitored GWIC Wells)
Injection Well
Water-supply Well
Gillam Properties
Model Domain

N

0 Feet 10,000

Figure 3
Model River Reaches

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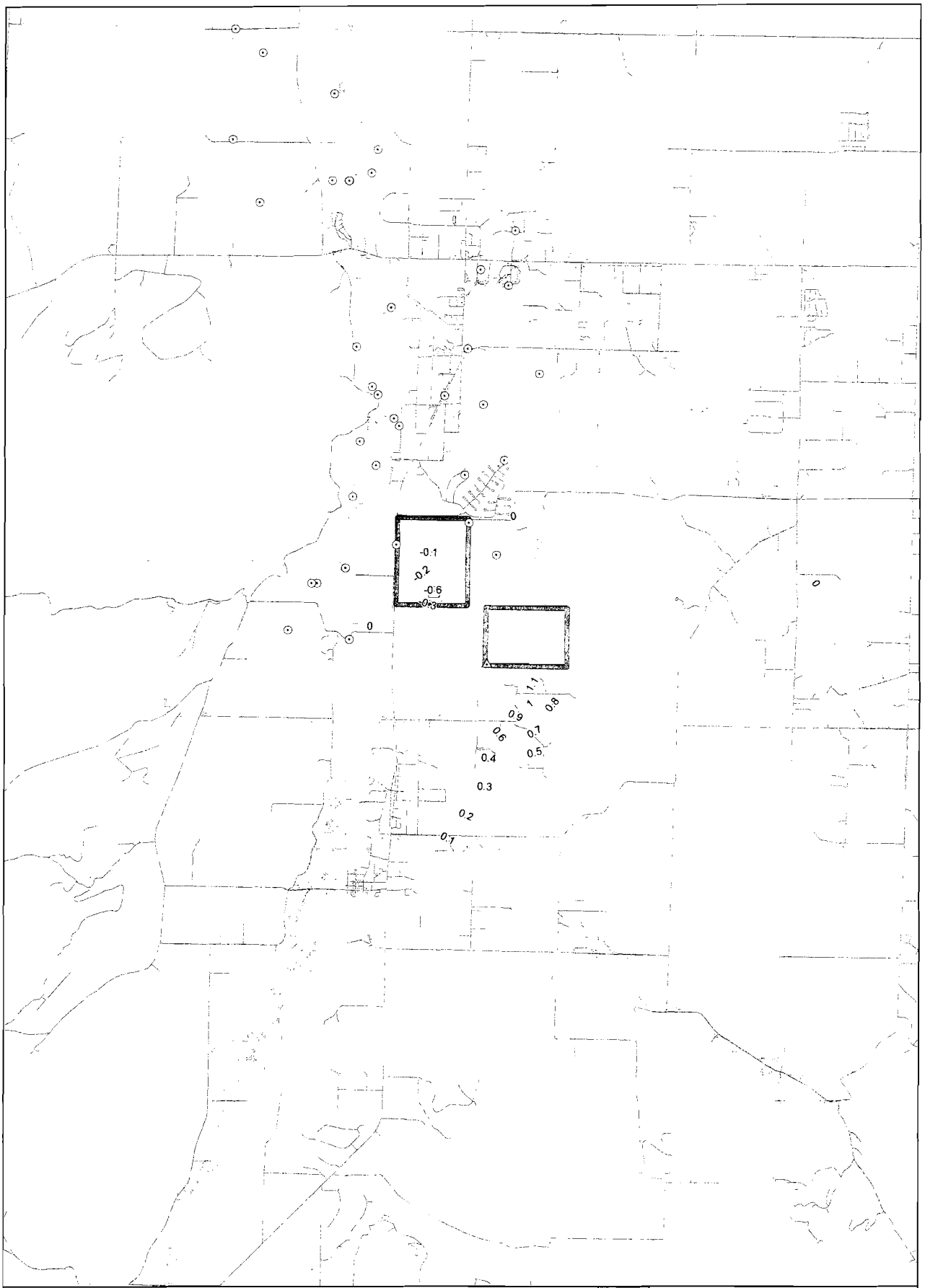

Model Estimated Water-level Change for End of April
Negative = Drawdown in Feet
Positive = Mounding in Feet

Head Targets (Monitored GWIC Wells)

Injection Well

Withdrawal Well

Gillam Properties

Active Flow Cells

River Cells

No-flow Cells

N

0 Feet 4,000

Figure 4
Simulated Water-Level Changes at End of April for ASR Scenario

P G

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