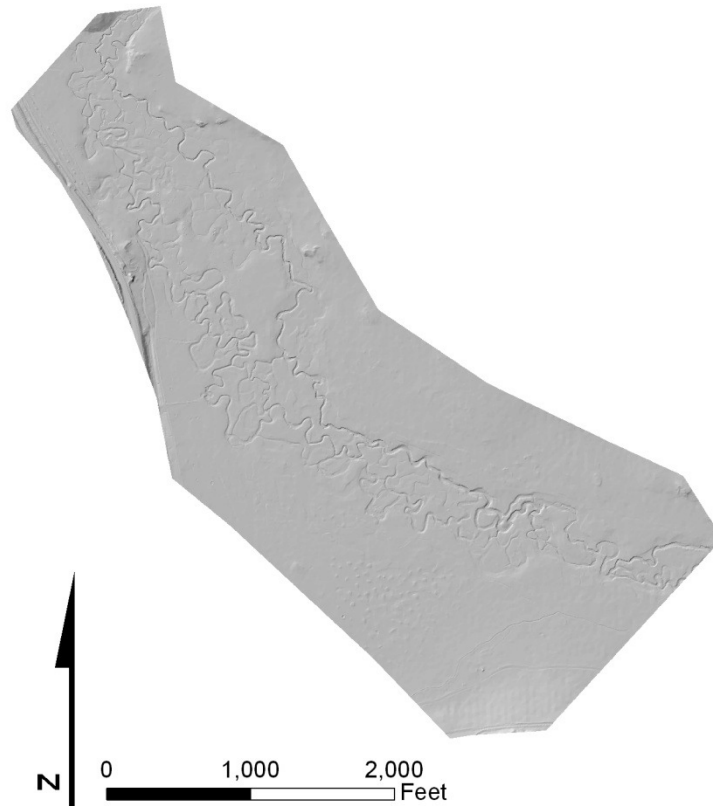


Kegg Meadow Groundwater Study

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For:
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Klamath National Forest
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Kegg Meadow



ABSTRACT:

Kegg meadow, of which Butte creek flows through, is currently vegetated by xeric species such as sage brush and bunch grasses. Riparian habitat is limited in the meadow. This study aims to understand the geology and groundwater processes of Kegg meadow and synthesize previous stream alterations and vegetative changes to inform the decision on rehabilitating the meadow to facilitate riparian conditions. Air photos were flown and topographic maps produced. Slug tests, soil augering and water table measurements were used to understand the groundwater and geology below the immediate surface and modeled to understand groundwater flow. Comparisons of the current and old channel properties were done using air photos and ArcGIS. The meadow exists because of a shallow perched hyporheic zone caused by a clay-cemented fluvoglacial layer. The diversion of Butte creek to the old channel is in line with the Forest Plan Management Direction for the Orr Lake Management Area. The old channel displays superior complexity and its reduced groundwater velocity should raise the perched groundwater table, allowing for more conducive meadow vegetation. The alteration in groundwater/surface water interactions is not expected to impact surface water at the end of the meadow.

GLOSSARY OF TERMS:

Aquitard: A layer of low permeability sediment that restricts flow of groundwater from one aquifer to another.

Hydraulic conductivity: Establishes water's ability to move through the sediment and it is dependent on the intrinsic permeability of the soil or rock as well as the degree of saturation.

Hydraulic head: A measurement of water pressure usually measured as a water surface elevation (ft)

Hyporheic Zone: The region beneath a stream bed where there is mixing of shallow groundwater and surface water.

Influent: A stream that contributes water to groundwater; also known as a losing stream.

Hydrostratigraphic Unit: Is a unit of rock with similar hydraulic properties and form a distinct hydrogeologic system.

Permeability: A measure of the ability of a porous media to allow fluids to pass through it.

Porosity: The percentage of rock or soil that is void of material.

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer. It is a function of properties of the liquid, the porous media and the thickness of the porous media



INTRODUCTION:

Kegg Meadow is located within the Goosenest Ranger District of the Klamath National Forest in Northern California. It is situated north of Orr Lake and Orr Mountain; east of Mt. Hebron and south of Shafter campground. Cascade volcanics dominate the rock types of the region.

Butte Creek is a perennial stream that runs through the study area. The system is largely snowpack driven. It is the largest stream within the basin, draining an area of 178 miles with an annual surface runoff of 13,000 acre feet recorded at a gauge near Orr Mountain [Department of Water Resources 1973]. However, this is only 10 percent of the water that falls within its watershed [Department of Water Resources 1973]. This makes Butte Creek an influent stream, which are common within semi-arid to arid climates. Losses within the channel of Butte Creek were mostly due to seepage, evaporation and plant transpiration [Zander 1929]. The largest component to water-loss is due to water draining into the groundwater basin through the extremely permeable volcanic deposits. Though Butte Creek originates within mountains northeast of Mt. Shasta, it appears to incur most of its water loss within Butte Valley [Department of Water Resources 1973, Wood 1960]. This makes Butte Creek a noteworthy source of groundwater recharge for the Butte Valley Aquifer.

Northwest-trending faults are prevalent within Butte Valley, essentially surrounding the area. However, the adjacent Mt. Hebron is cut by a northeast/southwest trending fault. This may be responsible for the bedrock outcropping on the northeastern section of Kegg Meadow, causing a narrowing of the alluvial floodplain as Butte Creek leaves the project area.

The productive aquifer hydrostratigraphic unit beneath Kegg Meadow is likely the permeable Tennant Basalt, the remnant of a lava flow that occurred around .5 million years ago [Hark 1978]. This flow serves as the primary aquifer for the area, though the Butte Valley Basalt serves as the primary aquifer for the region. These highly permeable deposits feature cracks and vertical joints that aid in transmitting water into the zone of saturation. The Butte Valley basalt has recorded specific capacities of more than 100 gpm per foot of drawdown [Wood 1960]. The Tennant Basalt is overlain by fluvio-glacial outwash deposits emplaced by a Pleistocene glacier flowing down from Mt. Shasta. This is largely a heterogeneous mix of gravel, sand and clay. The clay cement of this deposit gives this laterally continuous layer a relatively low permeability known as an aquitard.

The existence of Kegg Meadow relies on the retardation of water infiltration into the volcanic bedrock aquifer. This is likely caused by the low permeability of the fluvio-glacial outwash sediment, which slows, but does not halt, the downward movement of surface water into the regional aquifer. This creates a shallow perched hyporheic zone, satisfying the wet conditions necessary for a meadow.



Multiple alterations have been made to Butte Creek over time. Surface water is used for irrigation during the spring and summer seasons. Two creek diversions created by the Corps of Engineers as emergency flood control in 1965 divert water into storage reservoirs, allowing the surface water to drain into the groundwater system. One of these is located at Dry Lake and the other east of Orr Mountain. Later, the Butte Valley Irrigation District constructed a dam and canal for the latter diversion [Department of Water Resources 1973]. The Orr Lake dam also to keeps Orr Lake a lake year around. The most significant alteration relevant to Kegg Meadow was the diversion of water from the old stream channel to its current channel. This occurred sometime in the 1930's based on how the meadow was portrayed in maps from that time period.

There have been numerous effects caused by this channel diversion within Kegg Meadow. The current channel lacks the complex sinuosity and side channels present within the old channel (Figure 1). This has made portions of the current channel fairly incised, establishing its own lower floodplain. During episodes of high flow, the surface water now overflows onto the lower floodplain as opposed to the larger meadow. This leaves much of the valley floodplain devoid of the surface water it needs to recharge the shallow perched groundwater system. The fluvio-glacial outwash aquitard is no longer retarding as much water within the meadow, thusly lowering the perched water table. This has changed the plant life, with sagebrush and juniper now dominating the area. Because of the incised quality of the current channel, there is a distinct transition from the dryer vegetation to the meadow conditions. Air photos from 1948 show large patches of willow trees along the old channel (Figure 2). The photos were taken after Butte Creek had been diverted into the current channel. It is possible that this older channel once contained even more vegetation.

The Goosenest Ranger District is currently proposing a meadow restoration project in Kegg Meadow. The project entails re-diverting the surface water into the old channel. The water was diverted for irrigation purposes sometime in the 1930's. The Forest Service acquired the meadow in the 1990's. The desired future condition for Kegg Meadow as defined by the Orr Lake Management Unit is, "The areas of Upper and Lower Kegg Meadow support diverse meadow vegetation that contain highly productive late seral wetland plant communities (including hardwoods) maintained by a hydrologically functioning system and active water management. The water table is maintained within the rooting zone during the growing season. Dense vegetation provides stability to the stream channels." [USDA 1995]

The purpose of this report is to summarize the findings of the study and to answer three questions.

1. Characterize the shallow groundwater conditions in Kegg Meadow and build a conceptual model of the groundwater hydrology
2. Discuss potential impacts of proposed rehabilitation efforts to the groundwater
3. Discuss how rehabilitation will influence surface water within and downstream of Kegg Meadow



METHODS:

Air photos were flown over Kegg Meadow in September of 2010 at a 1:3600 scale. Using these, a 1 ft interval contour map and a digital elevation model (DEM) was created using photogrammetry. The current stream path as well as the old stream channel and side channels were digitized using the air photos and DEM. Six piezometers (shallow wells) were installed in the spring of 2011 (Figure 1). Wells 1, 3, 5 and 6 are made of 1" PVC piping and they were installed using a posthole digger and packed with sand. The radius of the well casing and screen is 1 inch and the length of the well screen is 12 inches. Wells 2 and 4 are made of 3/4" galvanized steel pipe and were driven in using a post driver. They have diameters of 3/4 in. diameters and the length of the screen is 12 inches. In April, May, July and August, the depth of the water within the wells was measured using a measuring tape. These were then mapped to show the head distribution throughout the meadow.

On July 26th, 2011, slug tests were performed on wells 1,3, 5 and 6 to calculate the hydraulic conductivity of the screened sediments. This consisted of using a well sounder to measure the initial water depth and then adding a volume of water to the well. The change in water depth over time was measured and recorded. (Figure 3). These measurements, along with well dimensions, find the hydraulic conductivity through the Hvorslev slug-test method using the equation:

$$K = \frac{r^2 \ln\left(\frac{L_e}{R}\right)}{2L_e t_{37}}$$

Where K is the hydraulic conductivity (ft/d), r is the radius of the well casing (in), R is the radius of the well screen (in), L_e is the length of the well screen (in) and t_{37} is the time it takes for the water level to fall to 37% of the initial change [Fetter 2004].

Multiplying the hydraulic conductivity by the aquifer thickness, we can find the transmissivity (ft²/day). General observations such as areas with standing water and vegetation were made in the meadow during the multiple visits. Sinuosity was calculated by dividing the channel length by the length of the meadow. . General slope was of the stream channel was calculated.

Augering to depths up to 5 feet was completed August 10th, 2011. Nineteen sites were augered, completing soil descriptions of the sediment as it was removed. Later, the descriptions were generalized into 3 categories: clay, sand and gravelly sand. Water table depths were noted if reached and modified percolation tests were completed every 3 augered holes. These tests involved augering a hole to a recorded depth and filling it with water, recording the amount of water drained over time. Soil descriptions helped determine an average porosity for the meadow. A porosity value of .30 was assumed to characterize the soils found in the auger holes.

Transmissivity, head distributions, saturated thickness and porosity estimates were used the Darcy Flow tool in the Spatial Analyst toolbox in ArcGIS 9.3.1. With these, flow direction,



magnitude and volume balance were estimated. Two-dimensional, vertically mixed, horizontal and steady state flow is modeled and head is independent of depth [ESRI 2011]. The equation used for these calculations is:

$$q = -K \frac{\Delta h}{\Delta l}$$

Where q is the Darcian velocity, K is the hydraulic conductivity and $\frac{\Delta h}{\Delta l}$ is the change in head over the change in length (also known as the hydraulic gradient) [Fetter 2004]. Several assumptions for the Darcy Flow tool were made. The porosity was assumed to be consistent throughout the meadow, at .30. The aquifer thickness was estimated by subtracting the elevation of Butte Valley (assuming that the Butte Valley basalt is flat lying) from the elevation of the well in Kegg Meadow. Additionally, bedrock on either side of the meadow was considered to be impermeable boundaries suggesting that no water moves from the meadow sediment into the surrounding bedrock.

RESULTS

The hydraulic conductivities derived from the slug tests were 8.77 ft/day for well 1, 46.8 ft/day for well 3, 9.2 ft/day for well 5 and 24 ft/day for well 6. These values were multiplied by estimated saturated thickness of the aquifer to find the transmissivity. These values were 1,723 ft²/day for well 1, 9,219 ft²/day for well 3, 1,843 ft²/day for well 5 and 4,992 ft²/day for well 6.

The sinuosity for the old channel is the length of the channel over the distance from the start to the end of the channel in the meadow. It was measured at 2.3. The current channel's sinuosity was measured in the same way and was lower, at 1.8.

Augered holes were 30 to 60 inches in depth, with soil assessments completed approximately every 8 inches. Clay, sand and gravelly sand depths, thicknesses and elevations can be found in Table 1 and Figure 4. The clay layer was generally 20 inches thick and the uppermost layer of soil. This was followed by sand and/or gravelly sand with average thicknesses of 12 to 15 inches.

A cross-section of part of the meadow was created from this data (Figure 5) Water table depth and elevation measurements within these augered holes (Table 3) show that the water table was never found at holes augered near the previous channel. Alternatively, the water table was measured at most holes near the current channel. Those depths were as deep as 57 inches and as shallow as 16 inches. A water table cross section comprised of 3 holes aligned perpendicular to the two channels showed the drastic drop in water table the farther the holes were from the current channel.

Head distributions from the slug tests can be seen in Figure 6. The Darcy flow output for groundwater velocity depicts the velocity magnitude of water moving throughout the meadow (Figure 7). The red indicates the slowest velocities and the green indicates the highest. The



general trend is that the highest velocities are nearest the current channel and the slower velocities are where the old channel is. In general the groundwater velocity is estimated to be between 0.1 and 1.5 feet per day (Figure 7). The model also provides a directional output for the groundwater in Kegg meadow (Figure 8). This displays that the groundwater generally moves in a northwesterly direction, mimicking the topography of the meadow.

Multiple visits were made from April through August and changes in the amount of surface water near the end of the meadow were noted. This portion of the meadow became increasingly saturated sequentially until August, where it has since dried significantly. In July, both the current channel and the old channel were filled with water in this area and much of the ground was noticeably saturated. Other observations included the locations of the few willows left within the meadow as well as the incised quality of some sections of the current channel.

DISCUSSION:

The goal of this groundwater study is to characterize the groundwater system in Kegg Meadow and to discuss the implications of meadow restoration on the system.

Characterization of the shallow groundwater conditions in Kegg Meadow and a conceptual model of the hydrology:

Due to the influent nature of Butte creek, the stream loses water to the shallow perched groundwater within Kegg meadow. It can be inferred that the stream, if diverted to the old channel, would continue to incur water loss to this shallow groundwater.

Throughout most of Butte Valley, the water loss of Butte creek drains into the permeable Tennant Basalt, which acts as the regional aquifer. This process is impeded within Kegg Meadow. A wedge of fluvioglacial outwash, deposited in the Pleistocene by a glacier as it retreated towards Mt. Shasta, limits groundwater recharge into the regional aquifer. This wedge is largely a heterogeneous mix of gravel, sand and clay. The clay cement of the deposit gives this laterally continuous layer a relatively low permeability. The retardation of flow into the regional aquifer by the fluvioglacial outwash creates the perched groundwater table. The shallow perched aquifer is what provides conditions suitable for a meadow.

Hydraulic conductivity data as well as modified percolation test observations characterized the meadow's ability to transmit water within the perched aquifer. Hydraulic conductivity essentially establishes water's ability to move through the sediment and it is dependent on the intrinsic permeability of the soil or rock as well as the degree of saturation [Fetter 2004]. In this case, areas surrounding the current stream channel transmit water much easier than measured areas near the old channel. The Darcy Flow model of groundwater velocity magnitude echoes this (Figure 7). In this figure, the red indicates the slowest velocities and the green indicates the highest. As mentioned before, Butte creek is a losing stream and thusly how this perched groundwater moves water is important.



Head data collected from water table elevations in wells and auger holes was used to determine the general hydraulic gradient of the meadow. Groundwater will move in the direction of lower head values. The Darcy Flow model within ArcGIS provides a visualization of Kegg Meadow's flow direction (Figure 8). This suggests that surface water from Butte creek that enters the groundwater flows in the same direction as Butte creek, to the northwest.

Soil characteristics determined during augering revealed a general stratigraphic homogeneity across the meadow (Figure 5), with clay as the uppermost layer followed by sand and gravelly sand. This does not correlate with the varied hydraulic conductivity data, which would suggest a greater variety of sediment properties across the meadow. It is likely that our characterizations (clay, sand, gravelly sand) were too oversimplified and missed the nuances of the meadow sediment.

Meadow vegetation such as willows requires high groundwater tables and water table decline can lead to 'desertification' of the meadow (Stromberg and Tiller 1996). The xeric vegetation of sagebrush and juniper exemplify that the meadow is currently not meeting these conditions.

The marshy conditions at the furthest extent of the meadow that exacerbated through July depict the confinement of the shallow aquifer as it nears the end of the meadow. Bedrock on either side of Butte creek laterally confines the shallow aquifer, resulting in groundwater being squeezed vertically to the meadow's surface. Because of this confinement, it can be expected that much of the groundwater derived from Butte creek is returned to the surface at the end of the meadow.

Potential impacts of proposed rehabilitation efforts:

There is evidence of extensive willow vegetation in air photos from 1948 surrounding portions of the old channel. This infers that Kegg meadow is capable providing for riparian vegetation conditions. These willows, for the most part, no longer exist and have largely been replaced by sagebrush and other xeric vegetation. As mentioned previously, willows require shallow water table depths. Where there are willows in Kegg meadow, water table depths are at their shallowest (site #'s 142 and 154 in Figure 4).

This suggests that the requirement for restoring meadow vegetation relies on raising the groundwater table. This can be accomplished through two different methods: increasing the amount of surface water entering the groundwater and reducing the velocity of the groundwater within the meadow. Both of these conditions can be met by altering Butte creek flow from its current channel to the previous channel.

Reducing the velocity of the groundwater within the meadow by switching channels will be satisfied because the hydraulic conductivity, and thusly the transmissivity, is much lower in the older channel than the current channel. This means that its ability to transmit water is slowed, suggesting that the amount of surface water entering the groundwater should overwhelm the amount leaving. The groundwater table will then, consequently, rise. Presently, the groundwater



table is much higher near the current channel than near the previous channel. This is likely because of the surface water seeping from Butte Creek into the shallow groundwater. With Butte creek flowing through the previous channel, the groundwater table will rise to an elevation higher than that of the current channel. Though the exact distance of this rise cannot be calculated, the presence of willows in some areas of the current channel implies that this rise in the perched groundwater table does not have to be extreme.

Increasing the amount of surface water entering the groundwater may also raise the groundwater table. Water diversions within Butte creek prior to its arrival at Kegg Meadow did not exist when flow was moved to the current channel. It's likely that less water reaching the meadow has contributed to the lowering of the groundwater table. However if flow is diverted to the old channel, its complexity may aid in moving surface water to groundwater. Flood plain inundation, when the creek's water overtops its banks, is one way to accomplish this. The current channel is incised in some areas, likely because of its lack of complexity. This has created a secondary lower floodplain, reducing the likelihood of recharge for the meadow. The old channel has a greater sinuosity (2.3 vs. 1.8), and therefore has a greater complexity. This increases the hydraulic roughness which will slow down the stream flow in the meadow. This reduced speed will increase the chance of Butte creek overflowing into the floodplain.

This plausible rise in the groundwater table should lead to improved riparian conditions. In addition to a more sustainable willow habitat, a higher groundwater table should allow for more marshy areas and wetter surface conditions that last for longer periods in the year. The abandonment of the old channel will impact the water table locally, but the impact on the groundwater table over the entire meadow will be negligible. However the subsequent benefits of the rise in the groundwater table because of the old channel will likely outweigh the local impact.

Influence of rehabilitation on surface water within and downstream of Kegg Meadow:

The diversion of Butte creek from its current channel to the old channel will, for the most part, leave the current channel dry. This excludes portions where the old channel and the current channel are joined. The enhanced complexity of the old channel will extend the flow path of Butte creek through the meadow, encouraging water loss from the channel into the shallow groundwater system. As mentioned previously, this will be beneficial in raising the perched water table.

Flow direction data (Figure 8) depicts that groundwater flows in the same direction as surface flow. This suggests that both surface water and groundwater should flow towards the end of the meadow. Bedrock on either side of Butte creek narrows the alluvial floodplain as Butte creek exits the meadow, confining the groundwater. This explains why surface saturation continued to increase through July at this end of the meadow. As the groundwater becomes more confined laterally, it is squeezed up vertically back to the surface. This returns surface water that had been part of the shallow groundwater. It is reasonable to suggest then that water lost from Butte creek



to the groundwater through floodplain inundation has a means of returning to the surface and reentering the stream channel. Therefore, we believe that water lost due to diverting Butte creek to the previous channel will be minimal.

CONCLUSION:

Kegg meadow currently does not meet the desired meadow environment as described by the Orr Lake Management Unit. We believe that diverting Butte creek flow from the current channel to the old channel will improve both stream and meadow conditions. The increased sinuosity, complexity and likelihood of flood plain inundation will provide desired stream conditions. Lower hydraulic conductivities should supply a higher groundwater table, allowing for more appropriate meadow vegetation. Groundwater flow paths similar to surface water and confining bedrock at the end of the meadow will minimize surface water loss at the end of the project area.

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Kegg Meadow: Current and Old Channels

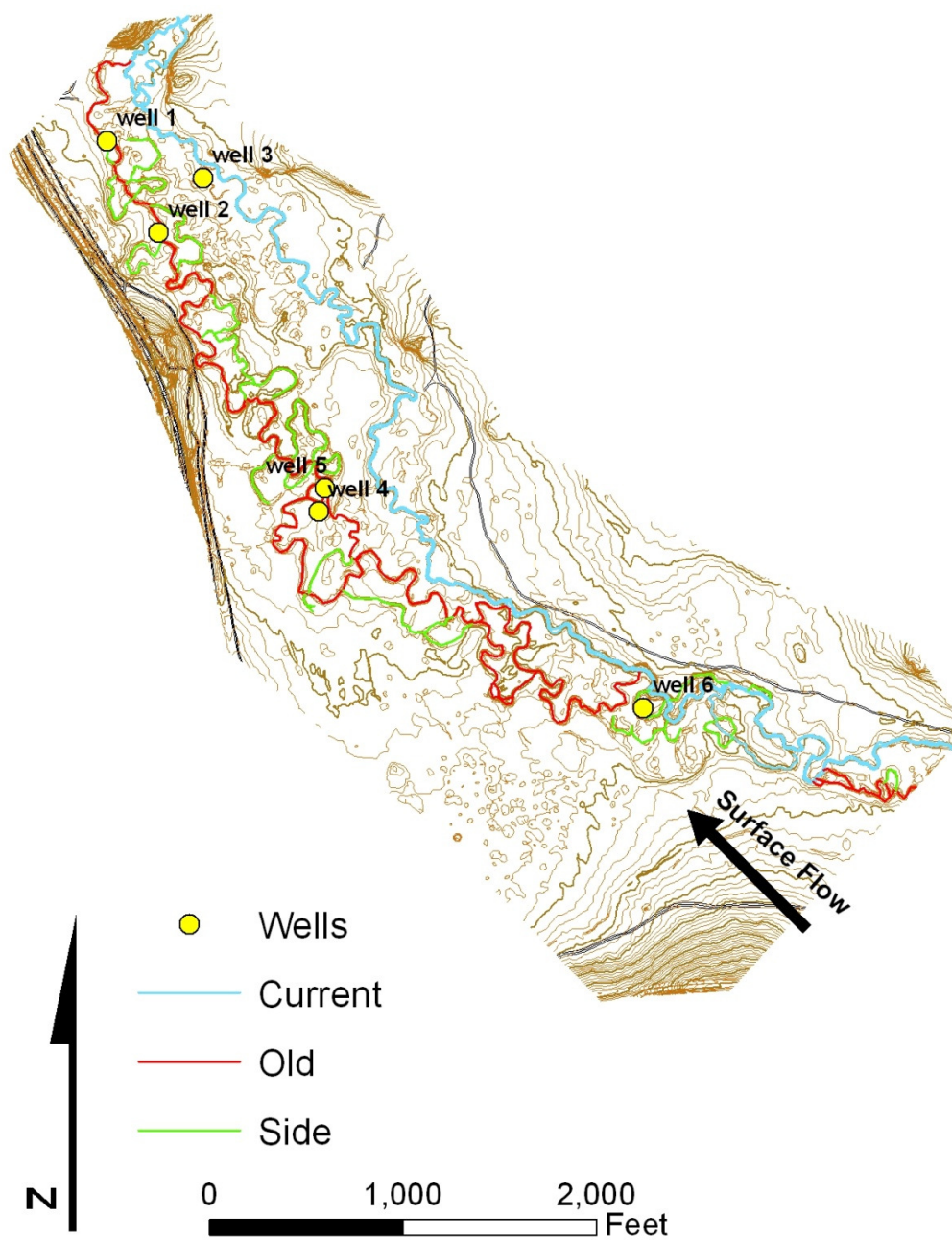


Figure 1: 2010 1 ft interval contour map overlain by digitized current and old Kegg meadow channels





Figure 2: Photo flown in 1948 over Kegg meadow displaying willow vegetation along the old channel (willow clusters highlighted in yellow). Surface water has already been diverted from the old channel to the current channel.

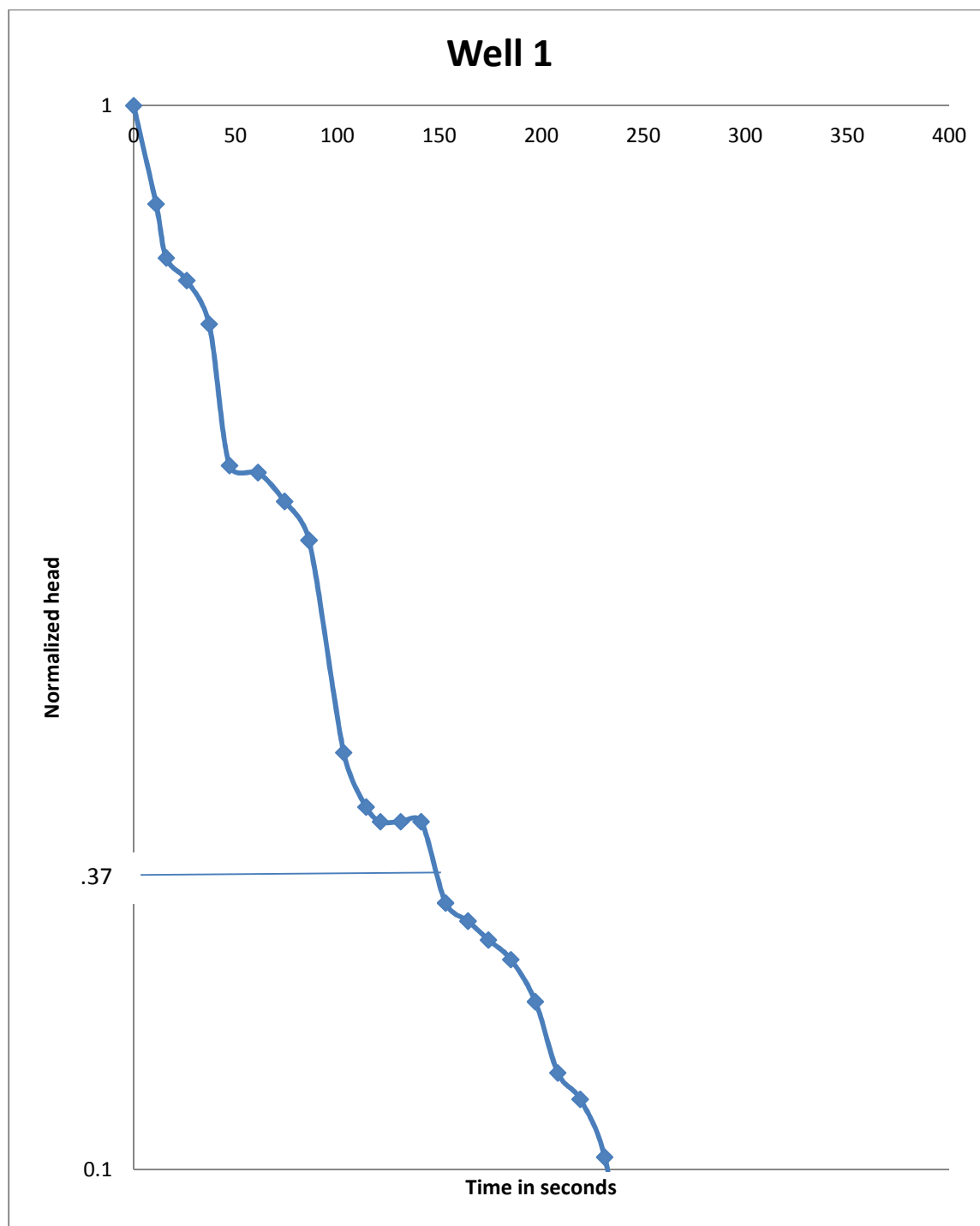


Figure 3: Slug test results displaying normalized head vs. time for Well 1. 0.37 line is used for finding hydraulic conductivity from slug test data.



Kegg Meadow: Auger Localities

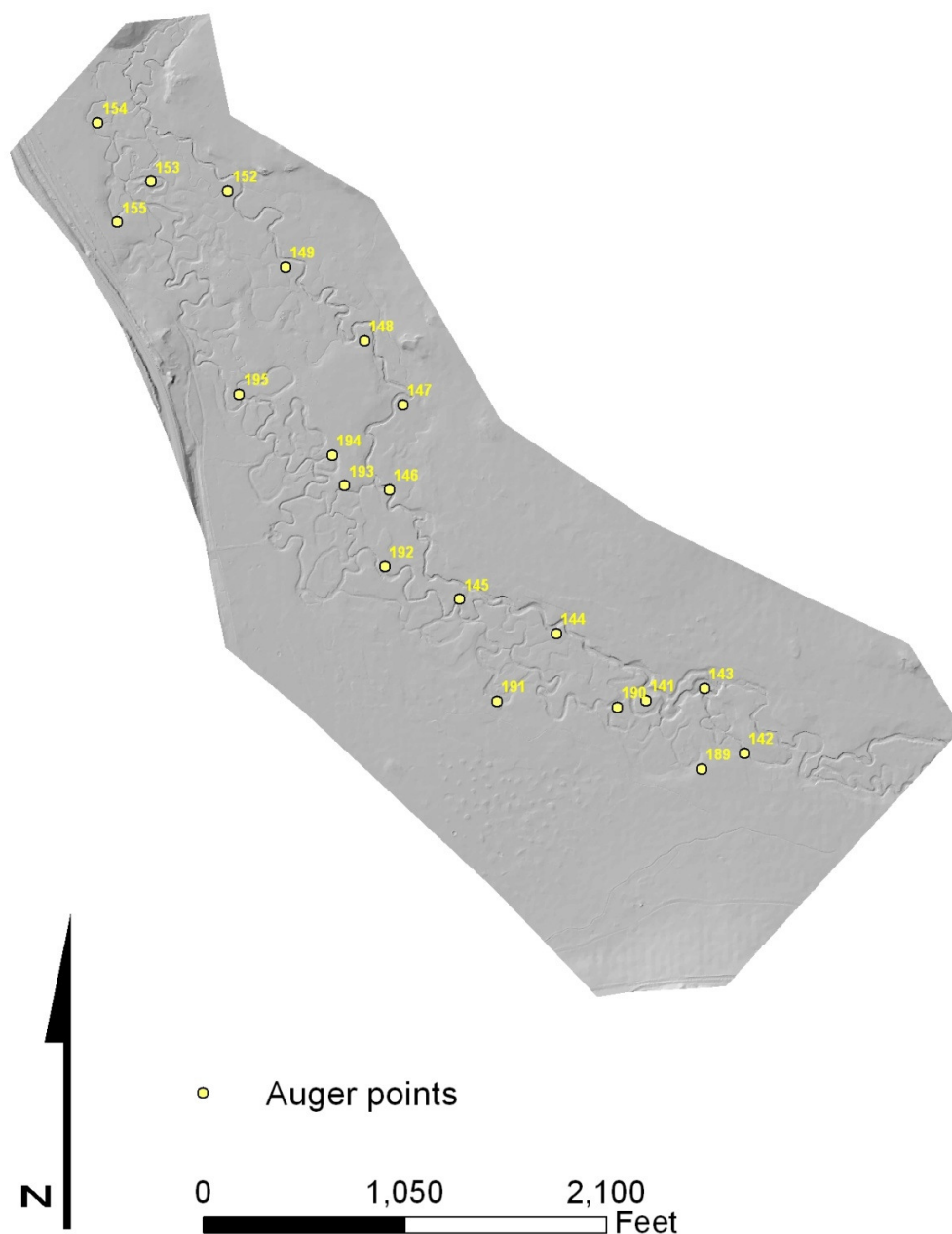


Figure 4: Labeled GPS points marking augering localities, can be cross-referenced with data in Table 1 and Table 2



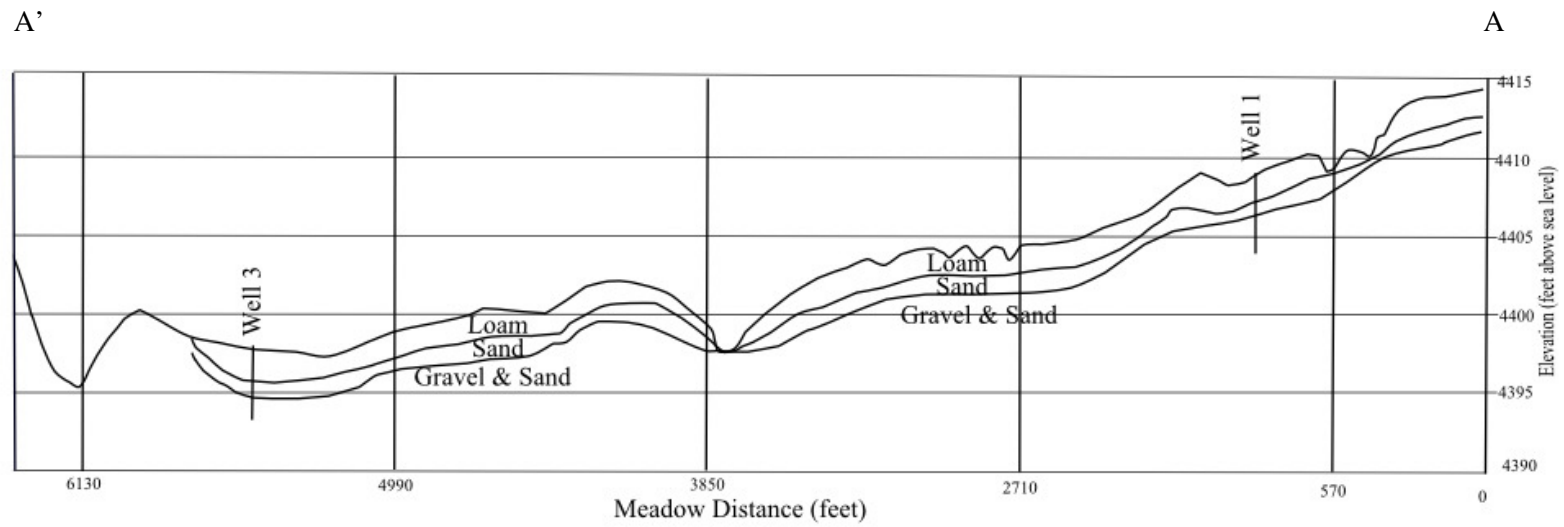


Figure 5: Cross section of Kegg Meadow created using soil data from Table 1



Kegg Meadow: Head Data (July)

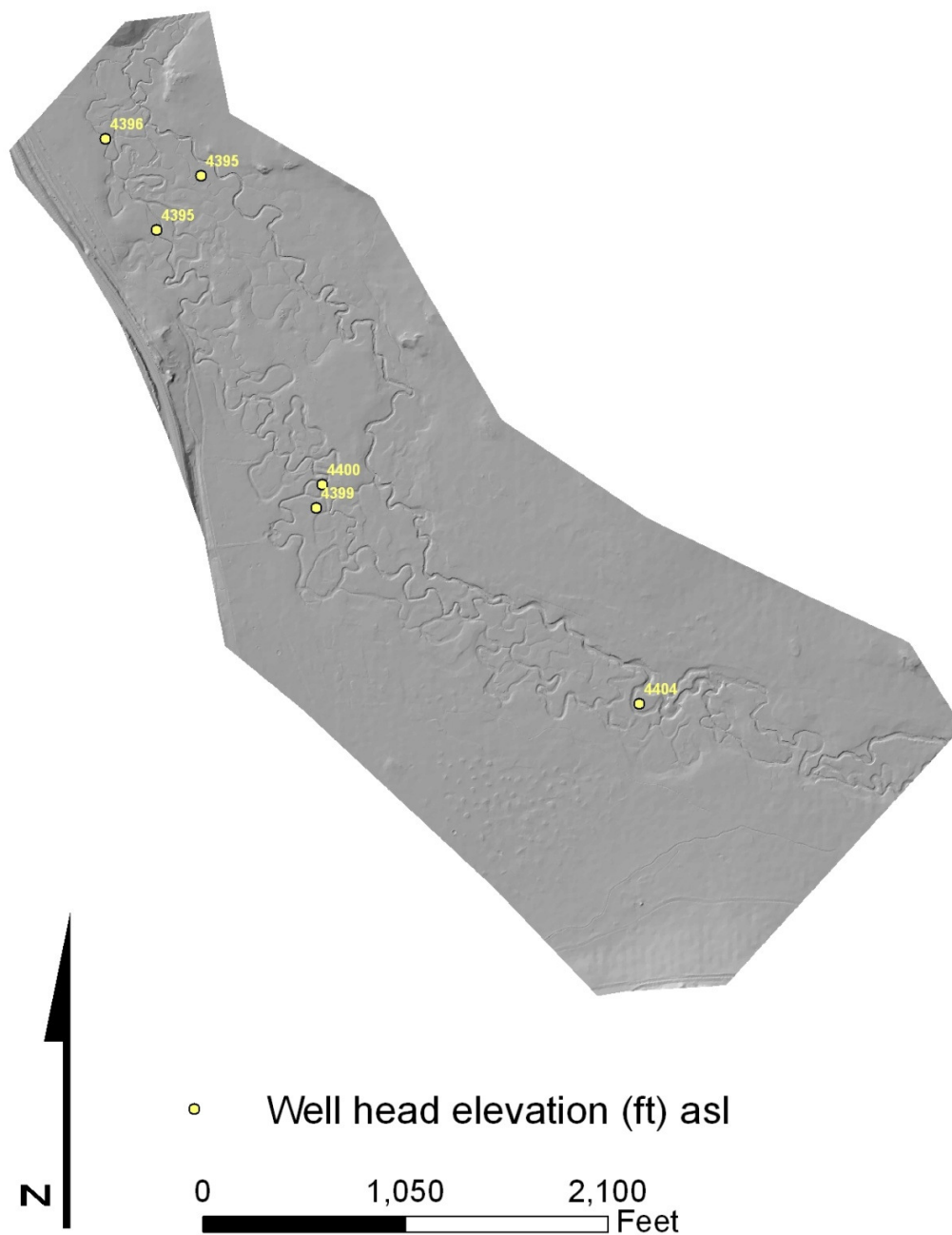


Figure 6: Head distribution as identified by groundwater levels within the 6 wells at Kegg meadow



Kegg Meadow: Groundwater Magnitude

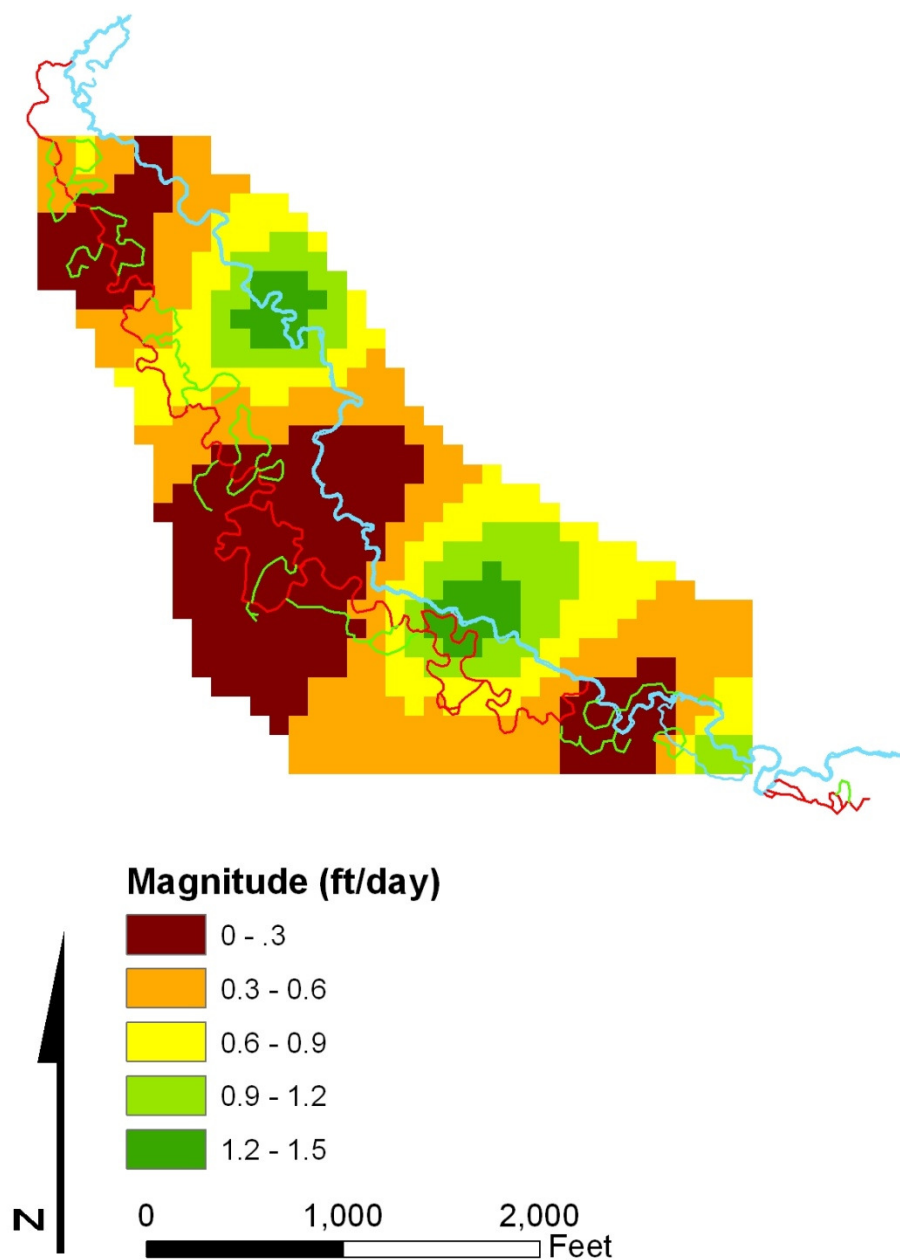


Figure 7: Groundwater velocity magnitudes, where red is the lowest velocity and green is the highest



Kegg Meadow: Groundwater Direction

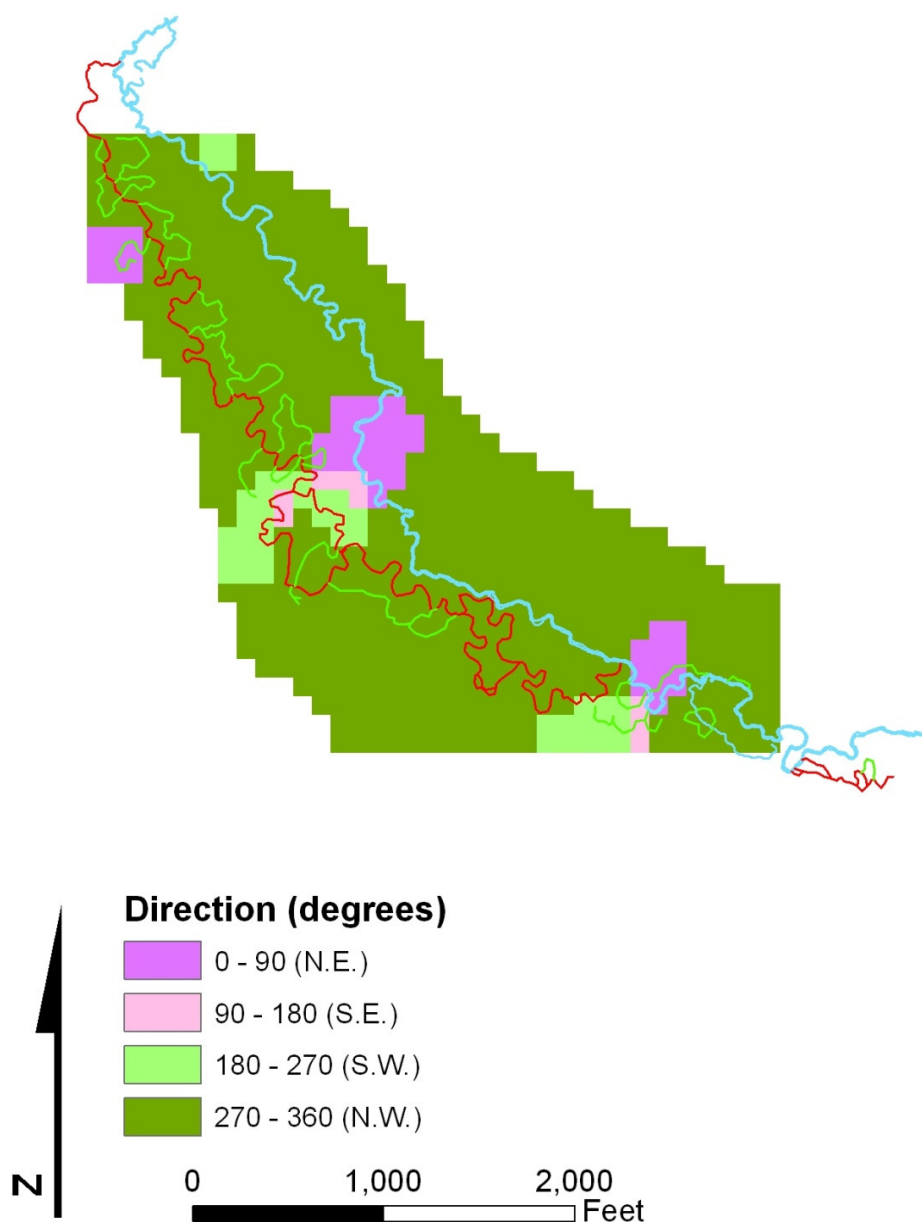


Figure 8: Groundwater directional flow model displaying the general NW trend of groundwater in Kegg meadow



Table 1: Auger data from Kegg meadow displaying elevation, thickness and depth from surface for the clay, sand and gravelly sand layers

GPS Point	Elevation (ft asl)	ELEVATION (FT asl)			THICKNESS (IN)			DEPTH FROM SURFACE (IN)		
		Clay	Sand	Gravelly Sand	Clay	Sand	Gravelly Sand	Clay	Sand	Gravelly Sand
142	4408	4405.7		4404.8	28		10	28		38
143	4408	4404		4403.4	48		8	48		56
144	4406	4403.4	4403	4402.7	32	4	4	32	36	40
145	4404	4402	4402	4401	24	6	6	24	30	36
146	4402	4400.7	4400	4398.6	16	12	13	16	28	41
147	4400	4399		4396	12		36	12		48
148	4400	4398.5	4398	4396.3	18	10	17	18	28	45
149	4398	4396.5		4395.5	18		12	18		30
152	4397	4396.5		4396	6		6	6	12	
153	4397		4394	4393.6		36	5		36	41
154	4396	4395	4394	4392.7	12	16	12	12	28	40
155	4399	4396.6	4395	4394	29	15	16	29	44	60
189	4412		4410	4409.2		25	9		25	34
190	4407	4405.4	4404	4403	20	21	7	20	41	48
191	4407	4406.2	4406	4405.6	10	2	5	10	12	17
192	4403	4402.3	4401	4399.7	9	15	16	9	24	40
193	4403	4401	4399		24.5	21.5		24.5	46	
194	4400	4399.4		4396.5	8		33.5	8		41.5
195	4400	4397.8		4396.6	27		14	27		41



Table 2: Hydraulic conductivity and transmissivity readings from wells within Kegg Meadow

Well #	Butte Valley Elevation	Elevation	Saturated Thickness	Hydraulic Conductivity (ft/day)	Transmissivity (ft ² /day)
well 1	4200	4396.5	196.5	8.77	1723.3
well 3	4200	4397	197	46.8	9219.6
well 5	4200	4400	200	9.2	1843.2
well 6	4200	4408	208	24	4992



Table 3: Water table data for GPS points displaying in Figure 4

GPS Point	Water Table Depth	Elevation	Water Table Elevation
142	16	4408	4406.7
143	40	4408	4404.7
144	57	4406	4401.3
146	33	4402	4399.3
147	26	4400	4397.8
148	26	4400	4397.8
149	18	4398	4396.5
151	39	4399	4395.8
152	20	4397	4395.3
153	32	4397	4394.3
154	26	4396	4393.8

Table 4: Well head data for each month of measurement

Well #	April	May	July
Well 1	4395.7	4395.2	4396.2
Well 2	4394.3	4395.7	4395
Well 3	4396.9	4396.1	4397
Well 4	4399.2	4400.8	4399
Well 5	4397.0	4398.9	4401.8
Well 6	4403.9	4404.8	4404

