

Technical Memorandum

Subject: Review of Alaska Department of Natural Resources
Detailed Statement of Findings and Decisions on Petition Requesting that the Streambeds of
Anadromous Waterbodies and Associated Riparian Areas in the Chuitna River Watershed be
Designated as Lands Unsuitable for All Types of Surface Coal Mining Operations

Prepared for: Trustees for Alaska, Cook Inletkeeper and Chuitna Citizens Coalition

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Summary

The Alaska Department of Natural Resources (DNR) has rejected the Chuitna Citizens Coalition and Cook Inletkeeper Jan. 21, 2010 petition to declare streams and their riparian corridors in the Chuitna River watershed as unsuitable for mining by claiming that best available reclamation technology would allow the establishment of pre-mining water balances. Even if an average annual recharge rate could be reestablished, it is the combination of site lithology and material properties that control the rate that baseflow discharges to the streams. The best available technology is concurrent excavation and backfill, which in the Chuitna watershed would excavate two aquifers that have different properties and thoroughly mix the material prior to backfilling it as mining proceeds. The current unique combination of groundwater storage, artesian pressure, horizontal and vertical conductivity, compaction and recharge cause the baseflow hydrograph that sustains streamflows during the low-flow periods of the year. The best available technology would dig up and remove the current layering and completely change the properties that control the flow through the backfill. Consequently, based on best available reclamation technology, it is not technologically feasible to restore water balances to pre-mining conditions.

Introduction

DNR rejected the petition to declare streams in the Chuitna River watershed as unsuitable for mining; the petition had been prepared by Trustees for Alaska on behalf of Cook Inletkeepers and Chuitna Citizens Coalition. This technical memorandum reviews the DNR's findings that consider hydrology in support of DNR's decision.

With respect to hydrology, reclamation must be able to restore the hydrologic balance so that recharge and discharge mimic the pre-mine rates. Myers (2011) presented a detailed conceptual model of the Chuitna watershed that outlines the factors which must be included in a successful reclamation. The DNR decision did not consider Myers (2011), and that report is again attached as an appendix to this technical memorandum and references herein are made to that report. . See Appendix 1¹.

Review of DNR Response Paragraphs

A site must be considered unsuitable for mining if reclamation cannot reasonably restore pre-mine groundwater conditions, including the hydrologic balance driven by recharge. DNR claims that reclamation is feasible and that it would reestablish groundwater in a “condition similar but not identical to the pre-mining condition.”

124. Petitioners' argument also overlooks the fact that state and federal agencies have made findings that reclamation in this area is technologically feasible. In the 1990 FEIS on the Diamond Shamrock Chuitna Coal Project, EPA stated that "[r]eclamation of the mine area would at least partly reverse the ground-water impacts from mining. After removal of the surface-water diversion systems, surface water together with incident precipitation would recharge the underlying spoil materials and with time result in the reestablishment of a ground-water regime similar but not identical to the premining condition." (DNR Para. 124)

DNR's claim is that a “ground-water regime similar but not identical to the pre-mining condition” could be established in the watershed after mining and that with proper planning “the impacts can be minimized.” A mine must be able to restore recharge capacity that (11AAC 90.343): “(1) supports the approved postmining land use, (2) minimizes and disturbance of the prevailing hydrologic balance in the mining area, and (3) provides a recharge rate approximating the premining recharge rate.” Although recharge rate is just one aspect of the “prevailing hydrologic balance,” DNR's performance standards rely on reestablishing the recharge rate.

Even if the historic steady state recharge rate could be reestablished, DNR ignores the lag time that the natural stratigraphy and lithology cause to the flow regime, factors which result in the unique timing of baseflow discharge to the streams. It is essentially impossible to restore the natural lithology as pits are backfilled and compacted (Paul et al 2007). Recharge must not

¹ Myers, Tom, Ph.D., *Baseflow Conditions in the Chuitna River and Watersheds 2002, 2003, and 2004 and the Suitability of the Area for Surface Coal Mining* (2011) was previously submitted to DNR for consideration with comments submitted by Trustees for Alaska. See Additional Comments in Support of the January 21, 2010, Petition to Designate the Streambeds of Anadromous Water Bodies and Riparian Areas Within the Chuit River Watershed, Alaska, as Unsuitable for Surface Coal Mining Pursuant to AS 27.21.260 from Austin Williams, Trustees for Alaska to Russell Kirkham, DNR, February 18, 2011 at FN 42, p.12.

discharge to the streams too quickly or the winter baseflow will be decreased to less than occurs at present. Postmining discharges to the streams must reestablish the premining exchange of water between the streams and the groundwater, through the hyyporheic zone (Hancock 2002), although surface/groundwater interactions are the most complex in hydrogeology (Sophocleous 2002). Myers (2011) describes the lithology and variability in groundwater levels that control the discharge of groundwater to the streams. DNR does not even address the timing of discharge or stratigraphy/lithology of the aquifers.

DNR's FEIS quote is selective; the following paragraph from the 1990 FEIS contains a more-complete discussion.

Reclamation of the mine area would at least partly reverse the ground-water impacts from mining. After removal of the surface-water diversion systems, surface water together with incident precipitation would recharge the underlying spoil materials and with time result in the reestablishment of a ground-water regime similar but not identical to the premining condition. It is anticipated that the water quality might be somewhat poorer than the premining quality due to the nature of the spoil material, e., intermixed clay, sand, and gravel. That is, the ground water would likely shift from calcium bicarbonate type to calcium and sodium sulfate type associated with an increase in total dissolved solids. However, the premining condition of progressively lower water quality with depth could persist in the reclaimed spoil aquifer. *Postmining aquifer properties would also vary from premining conditions; however, this impact would not be expected to adversely affect the regeneration of the postmining hydrogeologic regime since the subsurface materials would probably be permeable and have some capacity for storage and transmission of ground water.* The reestablishment of the ground-water regime and, in turn, reestablishment of the surface streams would likely require decades. This is governed by the necessary condition of establishing an equilibrium between the ground-water and surface-water regimes. If an equilibrium condition similar to the existing condition cannot be established, then maintenance of the **baseflow** contribution to streams during low flow periods might not be achievable. The elevation of the shallow aquifer water table relative to postreclamation ground surface elevations cannot be predicted with sufficient accuracy to assure base flow contribution to restored stream channels. (1990 FEIS at 5-20, **bold** in original, *italics* added).

The FEIS does suggest that a recharge regime could be reestablished, but it also acknowledges that the groundwater elevations might not be achieved with sufficient accuracy to adequately maintain baseflow to the streams, critical for winter habitat. Baseflow is the most important aspect of reclaiming streamflows and, along with stream form, is the most important aspect of fish habitat. Failure to reestablish pre-mine baseflow is a failure to reestablish fish habitat.

In its decision, DNR additionally relied on statements in the 1990 FEIS to support its decision:

155. As stated earlier, one of ASCMCA's purposes is to *minimize* adverse impacts to the hydrologic balance, including the recharge capacity within the mine area, and this is reflected in 11 AAC 90.343. As expressed in the 1990 FEIS, the EPA concluded that the proposed reclamation was essential to minimizing adverse impacts and would facilitate recharge of the "groundwater regime similar but not identical to the premining condition." This finding is again supported by DNR's 1987 Permitting Decision to issue the permit for the Diamond Shamrock Chuitna Coal Mine. As required by AS 27.21.180(c)(3), the permitting decision found that there would be no material damage to the project or surrounding areas. (DNR Para. 155, *italics* in original.)

This paragraph continues DNR's selective quoting from the 1990 FEIS, while not addressing the need to reestablish pre-mining lithology so that discharge will be timed as occurs currently (Hancock 2002). DNR Para. 125 cites to the 1990 FEIS to state that "with proper planning, the impacts can be minimized" without citing one example of a mine reclamation that has completely rebuilt aquifers so that the amount and time of pre-mining recharge and discharge has been replicated to any extent.

125. Nonetheless, the petitioners selectively cite portions of the 1990 FEIS to assert that reclamation of wetlands and riparian areas is not technologically feasible. The petitioners cite statements that, at first blush, appear to support their allegations, but omit other statements that discuss potential impacts and proposed reclamation that ultimately negate the contention that reclamation of coal mining activities is not technologically feasible. For example, petitioners quote the following from the 1990 FEIS regarding impacts to groundwater: "Impacts to groundwater regime as a result of mining operations would be substantial and would affect recharge and discharge relationships; quantity, quality, and direction of groundwater flows; and quantity and quality of surface water." However, petitioners fail to mention two other key observations EPA reached: "These impacts are **unavoidable**; however, with proper planning, the impacts can be minimized." (DNR Para. 125, *emphasis added*.)

DNR claimed the petition selectively quoted from the 1990 FEIS regarding the infeasibility of reclaiming wetlands and riparian areas, but the FEIS acknowledges these major impacts are unavoidable. They are unavoidable because the most difficult aspect to reclaim is the hydrograph of stream baseflow, as pointed out by Myers (2011).

DNR paragraph 137 alludes to modern analytical tools which could be used to design the reclamation. Regarding groundwater hydrology, it refers to the groundwater model MODFLOW: "Modern groundwater models, such as MODFLOW developed by the USGS, are able to predict mining impacts to groundwater and instream flows, allowing a mine operator to formulate plans to mitigate potential water table declines and associated stream flow losses during mining, as well as proving a means to mitigate impacts after mining while groundwater

elevations naturally recover.” (DNR Para. 137). MODFLOW is a physically based groundwater flow model with parameters describing hydrogeologic processes. MODFLOW and other numerical models can simulate groundwater flow accurately if the structure and properties of the aquifer are known and there are observation data to which to calibrate the model, although the accuracy decreases with size of the model domain, as pointed out by the National Marine Fisheries Service (2007). The ability to simulate does not establish the ability to construct or recreate existing groundwater conditions, which requires much data and much uncertainty remains (Binley et al, 1991). MODFLOW can precisely simulate flow through aquifer sections that a mining company cannot construct. DNR paragraph 146 criticizes petitioners’ technical reports as not including sufficient data, being speculative, or being based on an assumption that no impacts at all are allowed.

It is also important to note that contemporary mining practices have also changed with the advance of new technology and increased understanding of reclamation processes. Contemporary mining practices require continuous monitoring and mitigation of reclaimed areas. The petitioners and the authors of the commissioned reports base their arguments on the erroneous assumption that no adverse impacts at all are allowed to fish and wildlife habitat, wetlands, and site hydrology as a result of surface coal mining operations. (DNR Para. 146)

The proposed mining technique in the 1990 FEIS is concurrent strip mining and backfill, the current best available technology which DNR alleges the petitioners did not consider (DNR Para. 160). The reclamation plan in the 1990 FEIS describes the backfilling operation, which would not reestablish pre-mine lithology as part of the reclamation. “After the initial box cuts have opened the pits for mining operations, the overburden and interburden material from the active mine areas will be backfilled by draglines and truck and shovel operations into the mined out areas” (1990 FEIS at 2-32). Concurrent backfill is the best available technology in 2011, just as it was in 1990. It will involve the removal of several hundred feet of overburden and interburden in addition to the coal seams. Such mining would completely remove the two primary aquifers at the site (Myers, 2011). Reviews of this type of backfill operation have found that hydrogeologic properties vary substantially from the pre-mine properties, mostly with the conductivity being much higher, porosity much lower, and with substantial preferential flow zones (Paul et al, 2007). Groundwater –surface water interactions depend on the joint effects of topography, geology, and climate (Sophocleous 2002); geology is the aspect of the premine condition that reclamation does not reestablish. The effects of dewatering an open pit site, especially in unconsolidated material, do not end at the pit or project boundary – lowering the water table substantially changes the flow paths in aquifers adjoin the site (Bonta et al, 1992). Even once backfilled, because of the changed hydrogeologic characteristics, flow paths in the backfilled mine will differ from that in the premine conditions so that flow paths in the adjoining aquifers can also be changed (Bonta et al, 1992). The long-term effects of open pit

mining extend far beyond the boundaries of the pit. It is not possible for backfilling a dewatered open pit to develop hydrogeologic characteristic similar to that which existed premine.

Although the final topography may resemble pre-mine contours, the crushing and mixing inherent with the operations just described assures that the backfill will be a relatively homogenous mixture of all lithologies, other than the coal, pre-existing on the site. There is no contemporary mining practice that minimizes the impacts of completely removing aquifers. DNR has provided no examples where degradation as complete as proposed for this site has ever been reconstructed. Monitoring would simply document the degradation.

The FEIS acknowledges that aquifer properties would vary from the pre-mining condition, but also states without reference that this would not “adversely affect” the “postmining hydrogeologic regime” because the subsurface materials would be permeable. This is no standard at all; any pile of waste would be permeable and allow recharge to flow through. To establish pre-mine hydrogeologic flow conditions, the layering and similar properties for many lithologic layers would also have to be reestablished. In order to reconstruct the pre-mine lithologies, it would be necessary to excavate overburden and interburden by layer, and to stockpile each separately. The overburden and interburden layers would be excavated separately to remove up to four seams of coal, but would be placed into one or two temporary stockpiles (Chuitna Coal Mine, Part D1) Operation Plan, at 6). Complete breakdown and mixing of the layers would occur from shoveling the interburden into trucks with payloads ranging from 150 to 400 tons using shovels that can move from 25 to 80 cubic yards per load (Id.).

For backfill, it would be necessary to handle the material a second time, backfilling it to pre-mine thicknesses and properties. The mine plan indicates that interburden, which is fine-grained materials of the Tyonek formation, will be backfilled into the bottom and the overburden placed on top of the interburden (Chuitna Coal Mine, Part D9: Backfilling and Grading Plan, at 3). The layering associated with the coal will be gone. Because the interburden is not highly consolidated, the coal seams control the vertical flow. Without them, it would be impossible to establish similar control.

Myers (2011) discussed this in detail. Even if an average recharge rate is reestablished, the most important aspect from a baseflow perspective is the rate at which the recharge flows through the backfill (Myers, 2011). The FEIS also acknowledges that it could require decades and that equilibrium “similar to the existing condition” is necessary for “maintenance of the baseflow contribution to streams during low flow periods.” Without the layering inherent in the Tyonek formation, this is impossible (Myers, 2011).

DNR improperly rejects the concept of a reasonable time to reestablish recharge capacity because DNR claims the regulations do not require this. “The petitioners assert that because “groundwater recharge capacity cannot be achieved within a reasonable timeframe, the performance standard at 11 AAC 90.343 could not be met. Specification of a reasonable time

frame is not set forth in the regulations” (DNR Para. 156). The regulations may not specify a reasonable time frame, but baseflow to the streams, an annual water budget, could be established reasonably quickly. Without the natural seasonal variability it would not be similar to pre-mine conditions. The natural seasonal variability in the groundwater levels in the watershed indicates the aquifers are rather small, with storage capacity on the order of the annual flux through them (Myers, 2011). Timing of baseflow depends on the lithology, as noted above and in Myers (2011); the lithology will result from the placement of the mine spoil, which as described will be a heterogeneous mixture of overburden and interburden. DNR has presented no references to sites or to studies which suggest that reestablishment of the natural baseflow variability could be possible.

DNR relies on the mining company meeting performance standards in 11 AAC 90.321 to protect “water quality and hydrology” (DNR Para. 161). Except for a and b, these standards apply during mine operations rather than to reclamation. The inability to restore the long-term hydrologic balance (11 AAC 90.321 (a)) has been discussed above. The next standard (11 AAC 90.321 (b)) requires that changes in groundwater depth and flow pathways be minimized; as discussed above and by Myers (2011), this performance standard would require restoration of the current lithology. Maintaining discharges to federal water quality standards (11 AAC 90.323) would not help in the reclamation of the site, and could require a permanent presence to treat discharge in perpetuity.

The 1990 FEIS states that there is no way to predict whether the new channels would have sufficient baseflow, DNR’s claims to the contrary notwithstanding. Referring to stream 2003:

It is the applicant's intent to restore permanent stable channels along the approximate original courses of these streams after reclamation using established engineering techniques. However, the backfill material on which the restoration channels would be formed cannot be compacted to the same degree as the original bed material of these streams and would be susceptible to some erosion and degradation until geomorphologic equilibrium were attained. Remedial stabilization measures would probably be required during the early years of restoration. Furthermore, there would be no guarantee that the post-reclamation water table would coincide with the elevations of the recreated stream channels. Therefore, while it would be possible to reconstruct stream channels having physical characteristics similar to the existing stream channels, there is no way to predict whether the new channels would have sufficient base flow through the upper reaches to provide year-round flow similar to that which now exists. (1990 FEIS at 5-29)

The 1990 FEIS indicates that stream shape would be approximated, but also that it is not possible to compact “the backfill to the same degree as the original bed material” or to guarantee pre-mine water tables or “sufficient base flow.” Rather than supporting DNR’s conclusion that the site is suitable for mining, the 1990 FEIS supports the opposite conclusion: the site is unsuitable

as regards the performance standard requiring that the natural hydrologic balance be reestablished.

DNR concluded there was insufficient data in the record to decide the site was unsuitable for mining.

172. In accordance with AS 27.21.260(c)(1), the evidence in the record is insufficient to require my determination that-- for water quality, quantity, and hydrology that may provide fish and wildlife habitat within the petition area-reclamation in accordance with ASCMCRA is not technologically feasible. Moreover, the evidence is insufficient to support the petitioners' allegation that surface coal mining operations would irrevocably alter the hydrology and aquatic productivity of the petition area, or the Chuitna watershed. (DNR Para. 172)

DNR also claimed that “there is insufficient evidence to support the claim that reclamation throughout the delineated petition area is not technologically feasible” (DNR Para. 186). In fact, the 1990 FEIS basically states that it is not possible to reclaim streams to their pre-mine conditions regarding baseflow. Concurrent backfill is the best available technology, but the 1990 FEIS indicated that it is not possible for the backfill to mimic pre-mine conditions. As also described above and in Myers (2011), a mining company must reestablish, in addition to long-term steady recharge rates, flow pathways in the backfill aquifers that will store and pass groundwater in a manner similar to that which preexisted the mine. This has never been done, and there is no evidence in the 1990 FEIS that authors of that FEIS believed it was possible to do so, and DNR has presented no examples of how it can be done nor where it has been done. The best available technology today does not provide the means to do this in the Chuitna Watershed where strip mining will occur at depths of hundreds of feet.

Reference

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APPENDIX 1

MYERS 2011 CONCEPTUAL FLOW MODEL REPORT

**Baseflow Conditions in the Chuitna River and Watersheds 2002,
2003, and 2004**

And

The Suitability of the Area for Surface Coal Mining

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Conclusion

The Chuitna River watershed is a remarkably diverse watershed with very complicated flow patterns that affect baseflow in the three study area streams – 2002 (Lone Creek), 2003, and 2004 – and all other streams in the watershed. Baseflow in these streams is a significant component of baseflow in the overall Chuitna River into which they discharge. Surface coal mining would affect each of these streams differently and restoration faces many obstacles because the hydrologic complexity must be restored. Complexity refers to the multitude of flow paths, sources, and discharges that combined cause the baseflow hydrograph in a stream. Because the inherent variability in the distribution of wetland types, soils, unsaturated zone properties, glacial till properties, and a vertically impermeable but horizontally conductive zone as found in the mineable coal sequence cannot be restored to its pre-development function and complexity, the Chuitna River watershed is not suitable for surface coal mining.

Baseflow to the streams depends on recharge that varies around the watershed and heterogeneous properties of the wetlands, soils, and glacial drift. It also depends on a relatively impermeable layer preventing the recharge from draining too deeply. Finally, it also requires a layer beneath the glacial drift with sufficient transmissivity and connectivity with upstream sources to pass groundwater from offsite to stream 2002. Specific requirements for the restoration of baseflow include:

- The distribution of wetlands across the watershed must be replicated – not necessarily in the exact location but in the same proportion and distance from discharge points with similar underlying soils.
- The pre-development topography must be replicated along with the wetlands.
- The distribution of properties in the glacial drift is critical to reproduce because they control the flow paths from recharge to discharge. The properties are conductivity and storativity. This means the general proportions of silt and clay found heterogeneously around the watershed must be replicated.
- The hydrologic properties of the underlying coal sequence must be replicated to prevent the recharge from draining too quickly and to allow flow from west of the site to pass through to Lone Creek. This means that a layer with very low vertical conductivity but with relatively high horizontal conductivity must be restored to the site. It must also connect to the offsite source of groundwater flow.

The important result of reclamation is the replication of the flow hydrograph, and not just an average baseflow rate. If the initial rate is too high, the groundwater storage may drain too quickly so that the rate at the end of the period could be too low to support the aquatic habitat. If the aquifer stores too little water, baseflow throughout the period will be too low. Alternatively, too much recharge or too much groundwater storage would cause the baseflow to be too high which may disrupt the sediment and temperature conditions in the stream. It is essential to replicate both the average and range in baseflow to restore aquatic habitat. Failing to replicate this hydrograph is a failure to restore the site. It is impossible to restore the complexity to the watershed as documented herein, and therefore impossible to prove that the pre-development aquatic habitat can be restored.

Introduction

The purpose of this work is to consider whether open pit or coal strip mines constructed in the Tyonek formation in the watershed of the Chuitna River can be restored to pre-mine conditions. Specifically, this report considers whether three aspects of the system can be restored – the water balance, the recharge rates, and the aquatic habitat as affected by stream baseflow. The study area is the Chuitna River watershed with a focus on the area between stream 2002 and stream 2004, northeast of the river. Figure 1 shows the general location and features of the study area, and Figure 2 shows existing coal leases in the area.

The key components of the water balance affecting the aquatic habitat are recharge and discharge – not just their average rates and general locations, but also the variability around the study site. The critical flows which must be restored are winter baseflow. Baseflow discharge to the river controls the ability of the river to sustain the fisheries through the winter baseflow period (Trasky, 2009), from December through March (Riverside 2009, 2010). The essential baseflow characteristic is of course the flow rate, but this varies through the winter in critical ways. The baseflow must continue to follow a hydrograph similar to that before development. If baseflow is too high the baseflow channel shape may change due to changing sediment transport; if baseflow is too low there may be reduced habitat. Both increased and decreased baseflow is undesirable, so the hydrograph must be restored to its pre-mining characteristics. To maintain the predevelopment baseflow hydrograph, it is essential that the following be accurately reproduced

- Recharge volume
- Recharge timing
- Groundwater storage capabilities in the unsaturated zone
- Groundwater storage capabilities below the water table
- Flow pathways
- Hydraulic conductivity

Beyond the actual recharge rate, the aquifer system controls the baseflow to the river. Restoration must be able to restore those aquifers to pre-development conditions. This report analyzes the stratigraphy and lithology of the area and uses existing groundwater and surface water data to assess the variability of recharge and discharge. The report presents a detailed conceptual model of flow from recharge to discharge and explains its several pathways. It also describes how mining would likely change those flows and discusses the details which would need restoration to return the area to pre-mining hydrologic conditions.

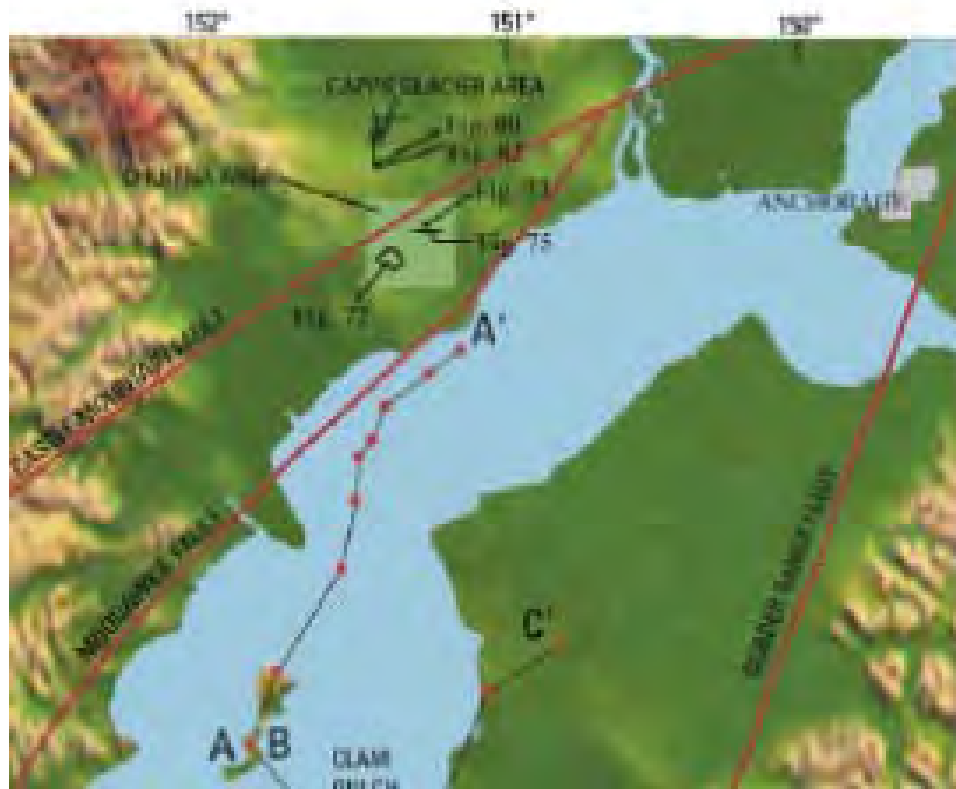


Figure 1: General location map of study area. Snapped from Figure 58, Flores et al (2004).

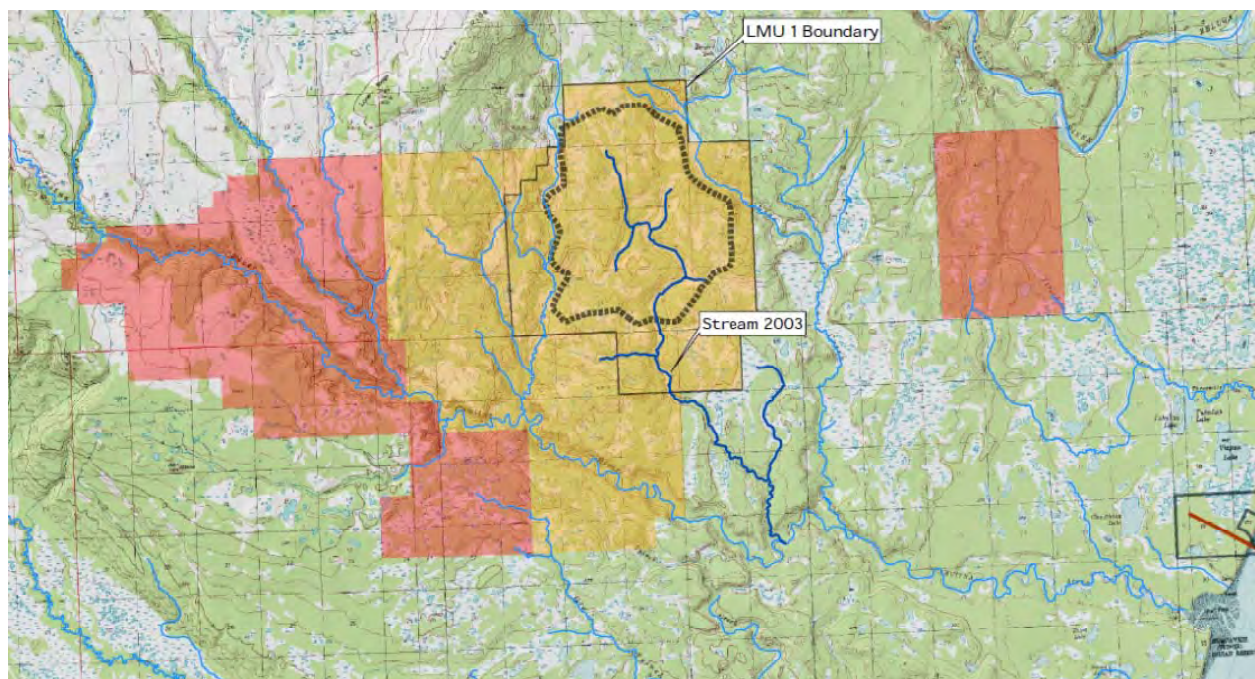


Figure 2: General topography of lower Chuitna River watershed. The red area is Barrick-owned leases, the yellow area is PacRim coal leases, and the dashed line outlines the proposed Diamond Chuitna Coal Mine.

General Geology, Stratigraphy and Lithology of Chuitna River Watershed Aquifer System

The general geology and surface feature map (Figure 3) shows two striking structural features, the Lake Clark (also known as Castle Mountain) and Bruin Bay Faults almost compartmentalize the underlying geologic formations. The formations change at the faults indicating the faults caused significant offsets, with the area between being downdropped. Erosion exposed different formations to outcrop. Northwest of the Lake Clark fault, the surface outcrops are Tertiary aged, including a substantial volcanic plateau (Tv). The Chuitna River eroded into the Tyonek Formation (Tkt) in the area between the faults and the Beluga formation east of the Bruin Bay fault. Surficial deposits, Qs, mantle the Tyonek and Beluga formations; these are the glacial drift deposits.

The fault-caused compartmentalization creates an area of similar geology which should have similar hydrologic characteristics. The Tyonek formation contains the mineable coal and glacial outwash from several glaciations has formed the glacial drift which mantles the Tyonek formation. The land generally drains in all directions to headwater streams that combine and flow southwest toward the Chuitna River. The leased areas (Figure 2) generally correspond to the area between the faults (Figure 3), which of course reflects the Tyonek formation being sufficiently near the surface that the coal seams could be accessed. Most of the data used in this analysis was collected for the Chuitna Coal Project, but it should represent the overall study area. This memorandum accepts the data in those documents, although Hecht and Bartholomaeus (2009) found them lacking in many areas.

There are two general groundwater flow systems within the study area, as defined for groundwater modeling (Arcadis, 2007), the upper and lower flow systems, respectively. They divide into four general aquifer layers at the site – from top to bottom these are alluvium and glacial drift in the upper flow system, and mineable coal sequence and sub red 1 sand in the lower flow system. Glacial drift is the term given to the glacially derived material, although some is till and some is outwash (Mine Engineers, 2008, p. 8). Below the glacial drift is the mineable coal and sub red 1 sand. The variable sourcing of the material contributes to its variable lithology, which in turn contributes to additional complexity in its hydrologic properties. The geologic and topographic complexity of a watershed combine to make the groundwater/surface water interactions more complex (Winter, 1998).

Stratigraphy and lithology are described as two distinct models to separate the flow into geologic formations, the stratigraphic layers, and between the individual layers within each geologic formation. The stratigraphic breakdown follows the convention established by the groundwater studies prepared for the project area (Riverside, 2010; Arcadis, 2007). The lithologic model recognizes that the stratigraphic formations have distinct layers with very distinct properties (such as the difference between coal seams and the sandy clay interburden).

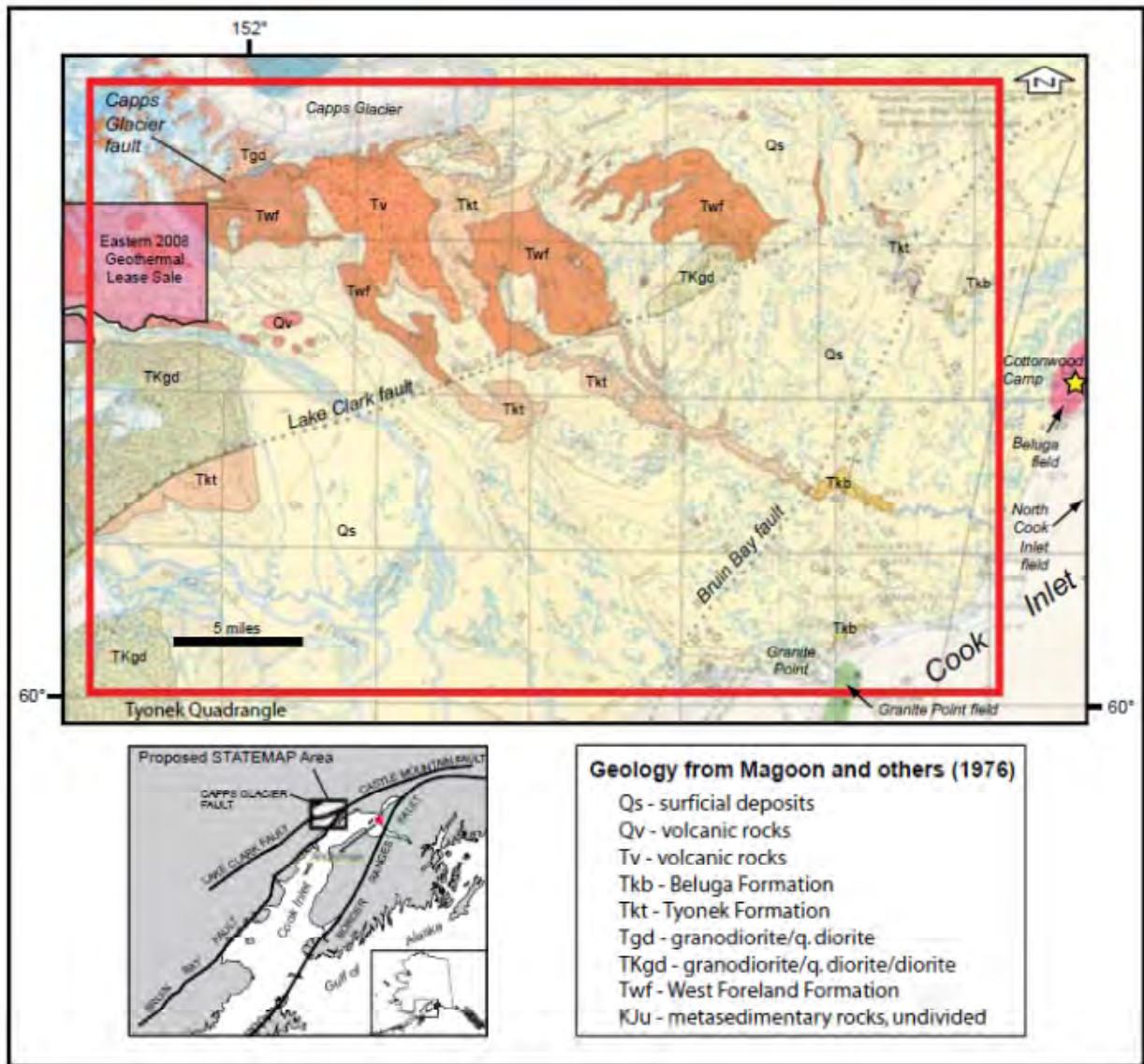


Figure 3: General geology of the Tyonek formation in the area south of the Beluga River, including Chuitna River. The Chuitna River lies in the NW to SE trending feature of Tkt and Tkb surround by mostly yellow Qs formation. Source: snap from Alaska Division of Geological and Geophysical Surveys, FY10 Project Description.

The complex lithology of the glacial drift (or overburden) was demonstrated in the geologic sampling around the study area (Mine Engineers, 2008, Table 2)². The “glacial drift to first coal seam” zone has coarse fragments over 16 observations ranging from 4.77 to 44.74%. Over 17 observations, the silt and clay percents vary from 12.6 to 52.1 and from 3.6 to 18.9% with averages of 30.1 and 10.7%, respectively. Other observations were equally variable. These variable soils control the flow through the glacial drift.

² It should be noted that Mine Engineers (2008) refer interchangeably to overburden and glacial drift, sometimes implying they are different formations although that is not what they mean.

The lower flow system coincides with the Tyonek formation, which consists of sedimentary rock such as sandstone and mudstone interbedded by coal seams (Flores et al, 2004 and 1994). The glacial drift lies unconformably on top of the Tyonek formation, indicating that some formations have been eroded prior to the deposition of the glacial drift. “The Tyonek Formation is a sequence of fluvial and deltaic silts, clays, and sands with occasional gravel beds and coal seams. It exhibits marked lateral and vertical facies changes, as well as extreme thickness changes, sometimes within very short distances” (PacRim, 2006, p. 7). This quote illustrates the complexity of this formation. The variable conductivity in the formation is apparent as well. “Fine-grained facies are dominant in some areas, while coarser grained sediments are dominant elsewhere. The entire unit appears to thicken westward and southward. Cemented zones are very rare, but most of the sediments have undergone substantial compaction. The sediments are more consolidated than would be expected from their present depth of burial.” (*Id.*).

The Tyonek formation in the study area has downdropped between two faults, causing the coal outside the faults to have been mostly eroded away. Although not constrained on all sides, the supposition that the faults impede flow (Arcadis, 2007) is reasonable. Because of the faults, the streams fed by aquifers within the project area depend more on local recharge than might otherwise be the case because the faults limit the flow, although flow does enter the area from the west through lower flow system.

There are at least 18 coal seams within the study area, but just four are substantial enough for mining – the Red 1, Red 2, Red 3, and Blue seams. The formation formed in a meandering river sedimentary system where overbank wetlands once buried become coal seams (PacRim, 2006; Flores et al, 1995); because they formed on terraces, floodplains, and isolated braids, they were frequently fragmented so there is little connectivity between many of the coals seams. Because coal seam hydrologic properties vary substantially both among themselves and from the surrounding interburden (Myers, 2009), the layering likely results in substantial differences in flow rate at different points in the formation. Figure 1 shows the general lithology of the Tyonek, or mineable coal, formation, but the figure fails to highlight the horizontal variability apparent in the formations description quoted above.

The alluvium occurs only along the stream courses, so the glacial drift is effectively the upper layer to the overall system and the upper flow system.

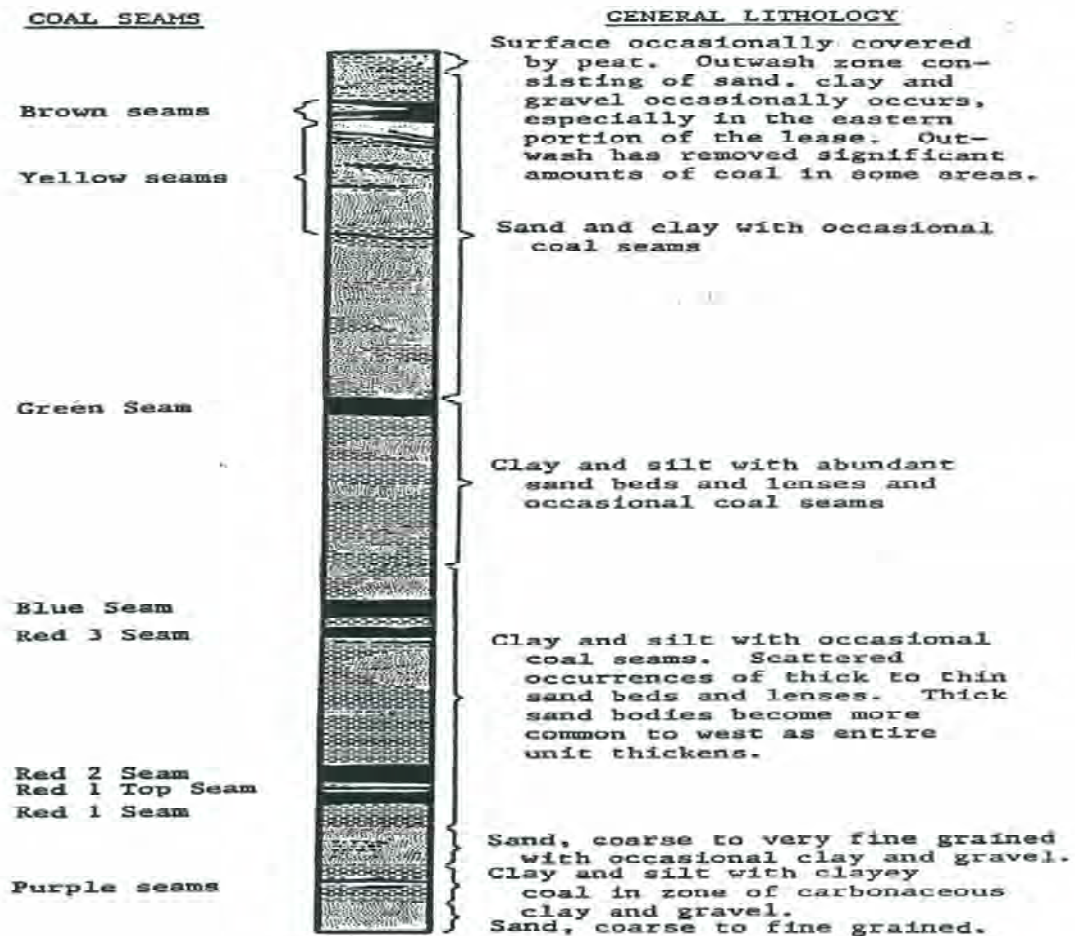


Figure 4: Snapshot from Figure 2 of PacRim (2006) showing general stratigraphy of the Tyonek formation.

Conceptual Flow Model of Aquifer Systems

A conceptual flow model is a description of the flow from source to discharge. Flow through the Chuitna River watershed system is conceptualized by considering the geology and topography, as discussed above, the groundwater levels in monitoring wells around the site in relation to the water levels in the streams, baseflow around the area, and aquifer transmissivity.

Groundwater Level

Riverside (2010 and 2007) and appendices provided the groundwater level data used to consider the conceptual flow in the study area. Monitoring occurred from 1983 through 1993 and again in 2006. Figure 5 shows the monitoring wells, by stratigraphy of their open interval, and the surface water monitoring points around the study area, as provided by Riverside (2009).

Long-term trends were generally not apparent in the data, so the hydrographs are not presented. The mean indicates the long-term average water level and standard deviation indicates the variability around that mean (Table 1).

The water table in the mineable coal and sub red 1 sand zones slopes from west to east, based on individual well observations (Figure 6). Riverside (2010, p. 4-23) suggests there is a transition from confined to unconfined conditions, in the coal, in this direction due to Lone Creek erosion having removed the mineable coal, although they also indicate the discharge to Lone Creek is minor. There are too few wells to confirm this observation, but 24D2 supports it and none of the wells contradict it.

The alluvial wells displayed the least variability, based on the standard deviation (Table 1). The sub red 1 sand wells were also steady. Most wells in the glacial till and mineable coal exhibited similar variability, although several specific coal wells had much higher standard deviation than the others (Table 1). Generally speaking, local aquifers would have more variability because they would respond more quickly to recharge. This would describe the glacial drift wells. The alluvium should also be a local aquifer but the intersection with the streams and the discharge from the glacial drift and mineable coal could stabilize the water level thereby decreasing the observed variability.

The groundwater level in the sub red 1 sand appears to be significantly lower than in the mineable coals, as noted by Riverside (2010, p. 4-22). Two well pairs demonstrate this. The level in the mineable coal is 765.3 and 582.1 ft amsl at well 22H and 22H1-U1, respectively (Figure 6). Similarly, the level is 762 and 685 ft amsl in the glacial drift and sub red 1 sand at wells 27G and 27G1U, respectively (Figure 6). The first well pair is about a mile northeast of the second pair, so they are not on the same flow path (from west to east) (Figure 5). Both suggest the existence of a downward gradient but neither indicates there is an unsaturated zone between the layers. The vertical gradient at 22H1-U1 indicates there is little hydraulic connection, meaning that pumping in the sub red 1 sand would likely not affect the levels above.

Groundwater levels in the glacial drift do not demonstrate a discernible slope because the glacial drift is eroded so these isolated aquifers discharge into the many channels and wetlands. The groundwater levels are generally higher than the surrounding stream elevations (Figure 6) so the flow is from drift to streams. Riverside (2010) notes the water levels are 8 to 72 feet below the ground surface and suggests the ponds and bogs are therefore not connected to the shallow groundwater. The standard deviation of water levels (Table 1, Figure 7) reflects the variability in water level in the glacial drift and indicates the water level rises and falls on the order of from 1 to about 6 feet on a regular basis. Variability could be due to variable recharge rates, with more recharge occurring in forested areas than in the bogs (Riverside, 2010). This change is about 5 to 20% of the saturated thickness.

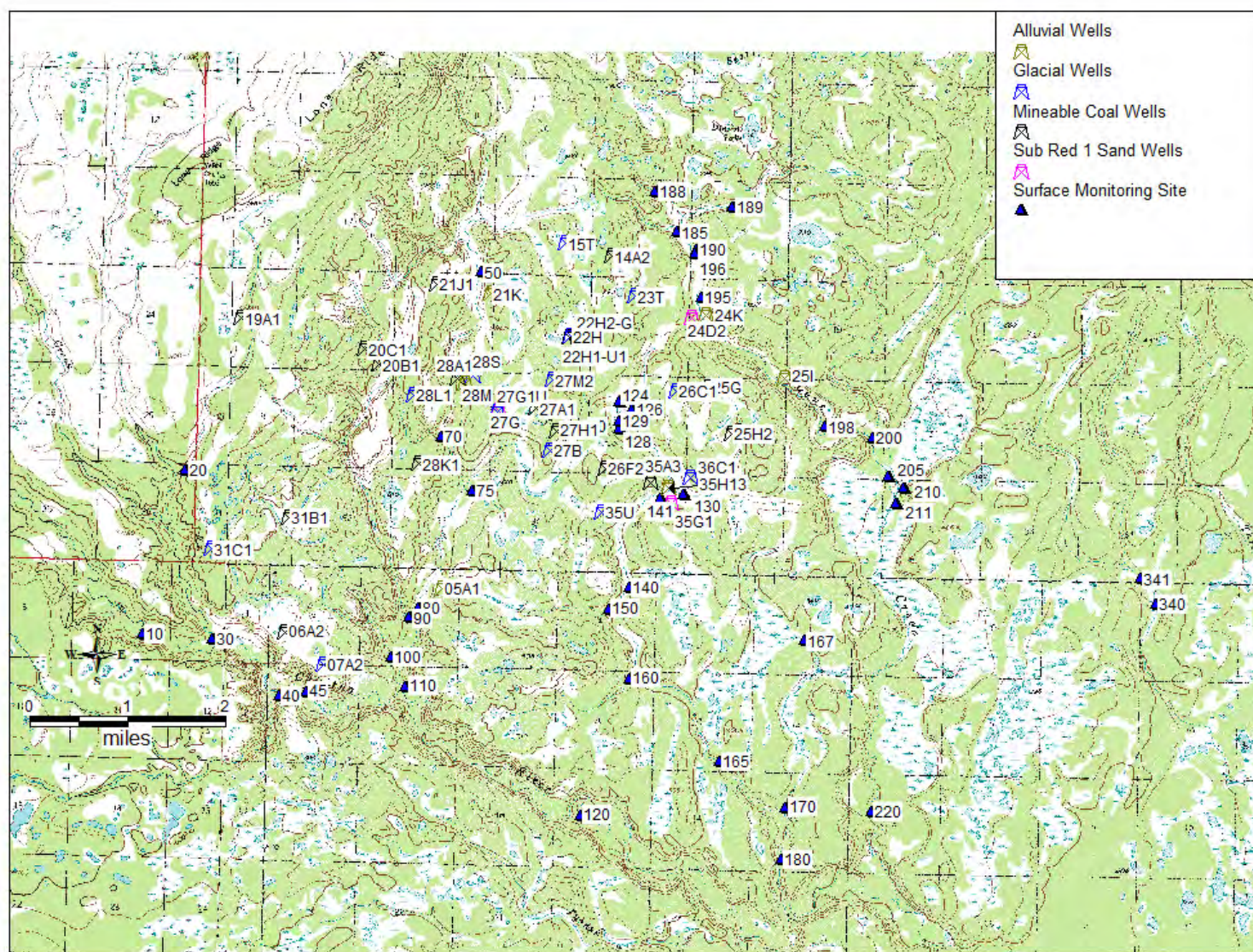


Figure 5: Location of groundwater and surface water monitoring sites, Chuitna River and Lone Creek project area. Source Riverside (2009 and 2010). Base USGS 1:24000 DRG

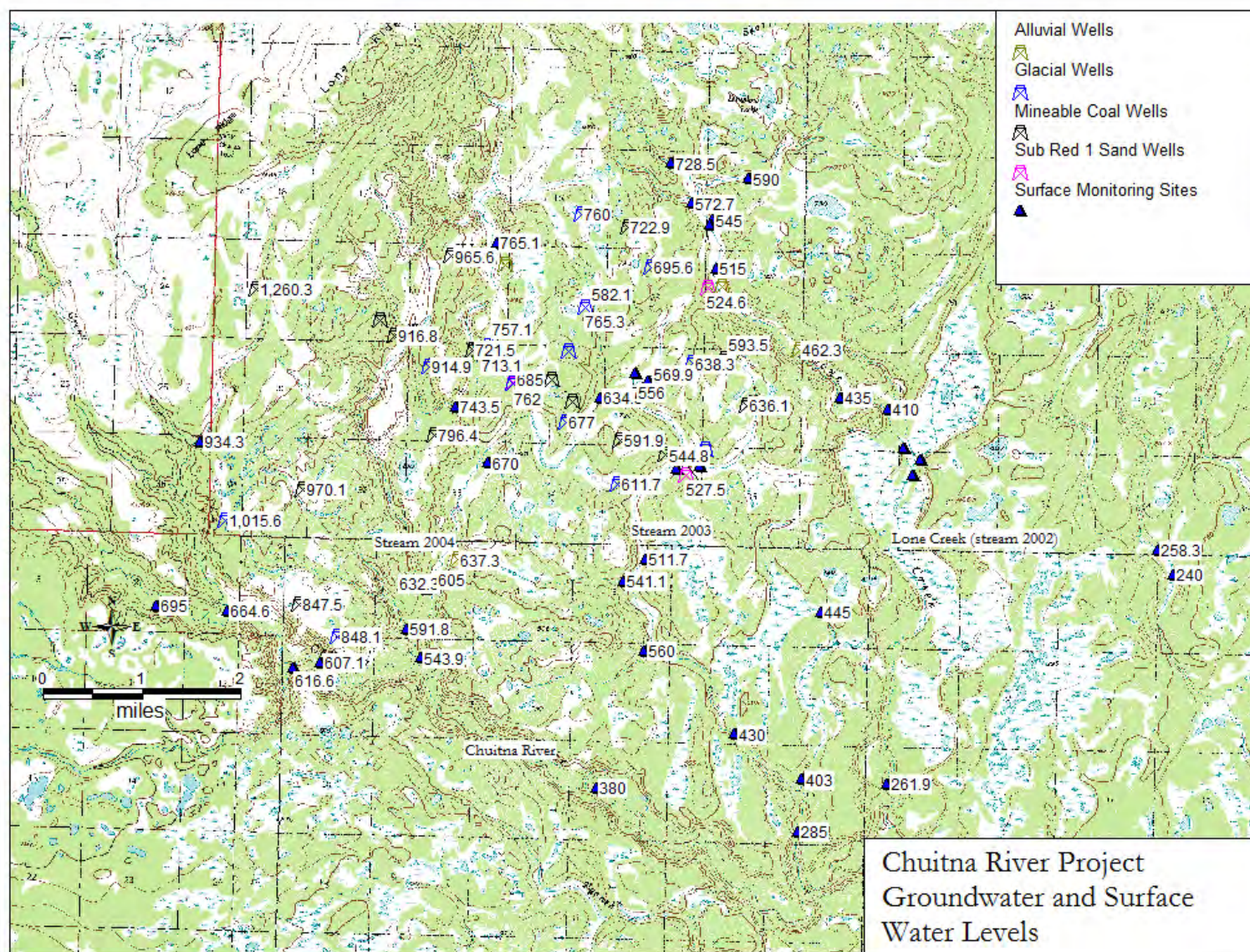


Figure 6: Groundwater levels and surface water elevations. See Figure 5 for sources.

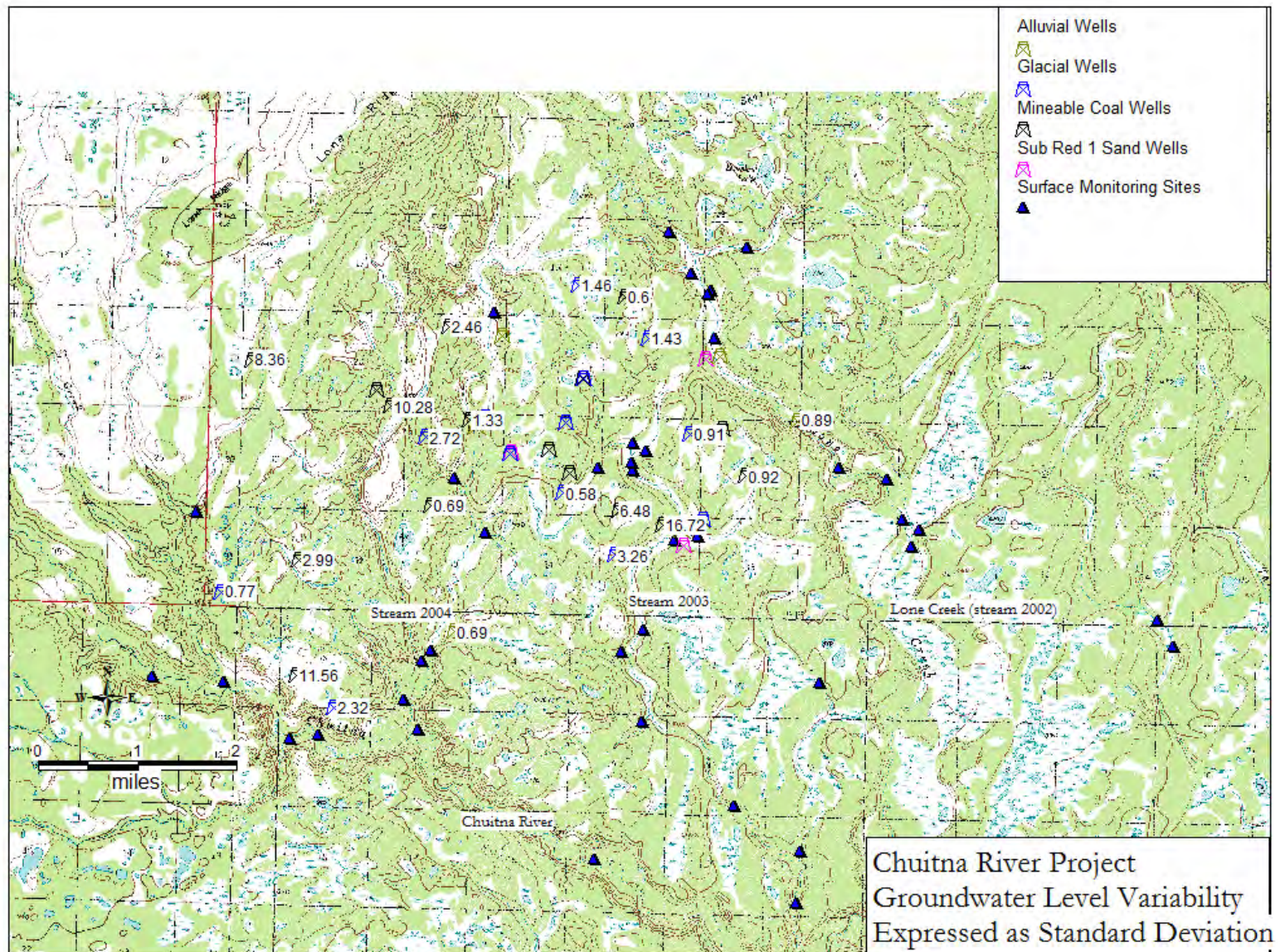


Figure 7: Groundwater level standard deviation. See Figure 5 for sources.

Table 1: Groundwater level and standard deviation for wells with coordinates and level hydrographs in Riverside (2010, 2007).

Alluvium	Count	Average GWEL	Std Dev
05A1	29	637.3	0.69
25I	18	881.3	0.89
28M	29	713.1	0.51
35H1	28	527.5	1.11
Glacial		689.8	
07A2	33	848.1	2.32
15T	13	760.0	1.46
23T	17	695.6	1.43
26C1	34	638.3	0.91
27B	7	677.0	0.58
27G	34	762.0	1.32
28L1	25	914.9	2.72
28S	17	757.1	3.93
31C1	6	1015.6	0.77
35U	18	611.7	3.26
Mineable Coal		768.0	
14A2	24	722.9	0.60
06A2	31	847.5	11.56
19A1	7	1260.3	8.36
20B1	34	916.8	10.28

21J1	33	965.6	2.46
22H	34	765.3	1.35
25G	33	593.5	24.80
25H2	31	636.1	0.92
26F2	34	591.9	6.48
28A1	32	721.5	1.33
28K1	32	796.4	0.69
31B1	31	970.1	2.99
35A3	27	544.8	16.72
Sub Red 1 Sand		794.8	
22H1-U1	27	582.1	2.77
24D2	33	524.6	0.70
		553.4	

The groundwater level variability as represented by standard deviation does not exhibit obvious inherent trends around the site (Figure 7). There is not one area or another with more than the average variability. However, the standard deviation in the glacial drift is higher in the center of the areas at points furthest from the creeks. It is here that the recharge into the drift causes mounds. Meteoric water infiltrates the glacial drift and flows downward until impeded at which point a mound forms. The mound increases the gradient and transmissivity for flow into the channels. Baseflow increases due to increased gradient and transmissivity and then decreases as discharge to the creeks (baseflow) depletes the mound. Discharge from the glacial drift decreases as the mound drops and lowers the flow gradient, which in turn slows the rate at which the mound is depleting in a negative feedback that helps to preserve the lower baseflow levels. In other words, as the baseflow reaches its lowest rates, the storage supporting that baseflow deplete much slower than just after the mound has been filled.

Standard deviation of water levels in the mineable coal is about the same as in the glacial drift although several individual wells have a much higher standard deviation, exceeding 10 ft², and several are lower

with values approaching zero. This implies that more recharge reaches the minable coal than previously thought because seasonal changes cause variability. However, the highest standard deviation values are near the streams, in wells 06A2, 35A3, 19A1, and 20B1 which also have groundwater levels much above those streams. This area of high variability coincides with the point of transition from confined to unconfined aquifer, where it discharges to the alluvium; inherently, the water levels in confined aquifer wells are more variable because the water level changes more for the same amount of groundwater removal due to different storativity values. The higher standard deviation therefore does not reflect more recharge to the coal but rather the combined effect of changing alluvial water levels and groundwater storage properties in a confined aquifer.

Baseflow Yield

Baseflow is river flow that occurs when there is no runoff or interflow. It is strictly groundwater discharge and a true expression of the average recharge to the system (Myers, 2009; Cherkauer, 2004). In the Chuitna River basin, groundwater discharge supports the aquatic systems during the winter, from December through March, when other sources dry. The baseflow yield would be the baseflow expressed as a rate, such as in/y. This section considers the baseflow from the entire Chuitna River and then uses data (Riverside, 2009) to consider how the yield varies around the study area to determine the variability in recharge around the basin or in the formations discharging to the rivers.

The USGS gaging station CHUITNA R NR TYONEK AK (#15294450) operated continuously from 1975 through 1986. The flows are seasonal with annual flood peaks up to 4000 cfs and winter baseflow as low as 30 cfs (Figure 8). Flows most years exceed 2000 cfs, often multiple times. The average flow rate over that period has 359.4 cfs.

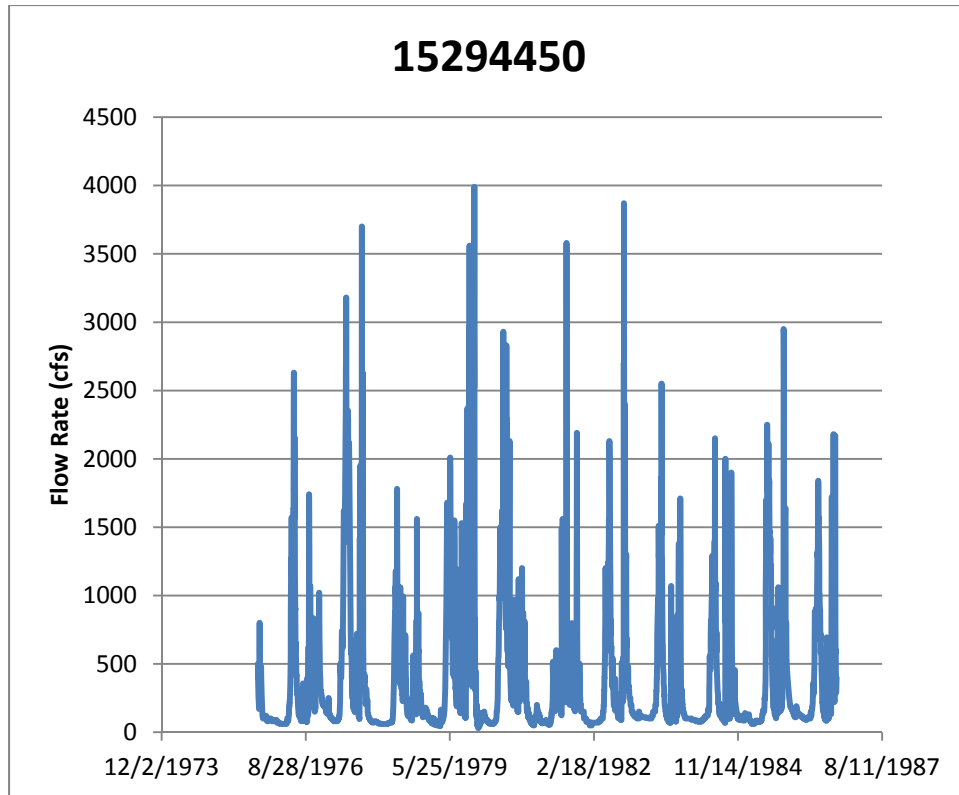


Figure 8: Hydrograph for the gaging station Chuitna River near Tyonek, #15294450.

December through March flow has not exceeded 200 cfs for nine of the ten years (Figure 9). The exception, (1976-77) had flow as high as 800 cfs in early December (Figure 8), probably due to a major late fall runoff event; the following baseflow discussion does not include that year nor is that year included on Figure 9.

Flow generally decreases through the baseflow period starting in December, but the obvious spikes probably coincide with warmer melt periods. The hydrographs do not show simple baseflow recession. The year with the lowest flow, 30 cfs in 1979-80 very early in the baseflow period, also experienced flow over 150 cfs (Figure 9).

Ignoring 1976-77, the baseflow yield rate for the 130 square (sq) mile basin above the gage is 9.2 in/y with a range from 6.9 to 12.1 in/y. The average baseflow, not including 1976-77, was 89 cfs. Assuming that baseflow is a relatively constant portion of the hydrograph over the entire year, the baseflow yield rate is 25% of the average flow at the site. Because of both the significant variation in baseflow yield and the variation in runoff, the yield rate proportion probably varies substantially from year to year and season to season.

Temporary gaging stations have been established around the proposed mine site for various periods since 1983 (Figure 5) (Riverside, 2009). The gaging periods are inconsistent but generally have some overlap. Baseflow at each station was determined as the average December through March flow (Riverside, 2009, Table 3.6). The total baseflow from streams 2002, 2003, and 2004, the sum of baseflow for C110, C180,

and C220, equals 36.2 cfs. The three watersheds that drain the proposed mine site therefore provide about 41% of the baseflow to the Chuitna River above the Tyonek gage.

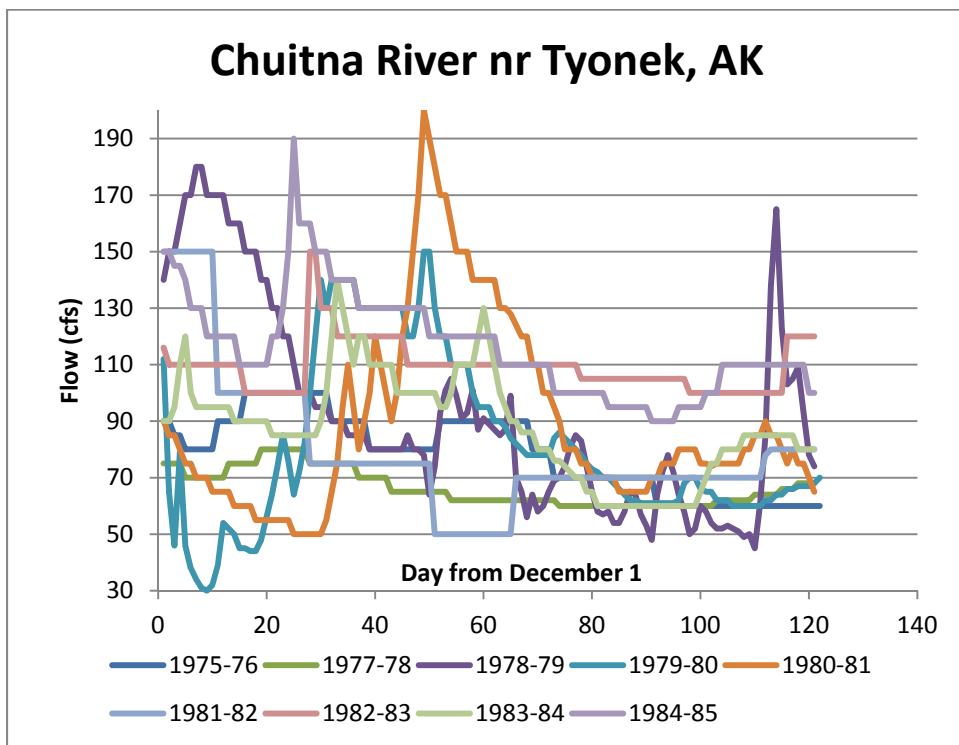


Figure 9: Baseflow for the Chuitna River nr Tyonek, gage # 15294450.

The baseflow yield has a few trends and observations apparent on the distribution around the basin (Figure 10). With one exception, the baseflow yields range about the same as the annual distribution of yield at the gaging station (Figure 9). The uppermost stations with ten years or more record all yield more than the downstream sections, again with one exception. Upstream site C195 on Lone Creek yields 13 in/y from 5.8 sq miles over 16 years. Site C50, draining 3.8 sq miles in upper stream 2004, yields 13.46 in/y and site 128, draining 3.8 sq miles in upper stream 2003, yields 12.5 in/y. The downstream sites all yield less (Figure 10). In general, the yield drops about 2 in/y between the upper and lower portions of streams 2003 and 2004, which may simply reflect a decrease in precipitation with lowering altitude because glacial drift is the primary cover throughout.

An exception is the 17.14 in/y at site C198 on Lone Creek, which has ten years of record and drains 7.8 sq miles, 2 sq miles more than the upstream station C195. This is an increase of more than 4 in/y from that upstream station. The intervening reach may have a mineable coal outcrop into the alluvium that adds flow from outside the Lone Creek drainage. If the additional flow had resulted from recharge in the intervening 2 sq miles, the necessary rate would have been 29.2 in/y. If the intervening 2 sq miles had a yield equal to that at the upper gage, the additional flow would be 1.9 cfs. Therefore, the mineable coal is discharging approximately 2.3 cfs to the stream.

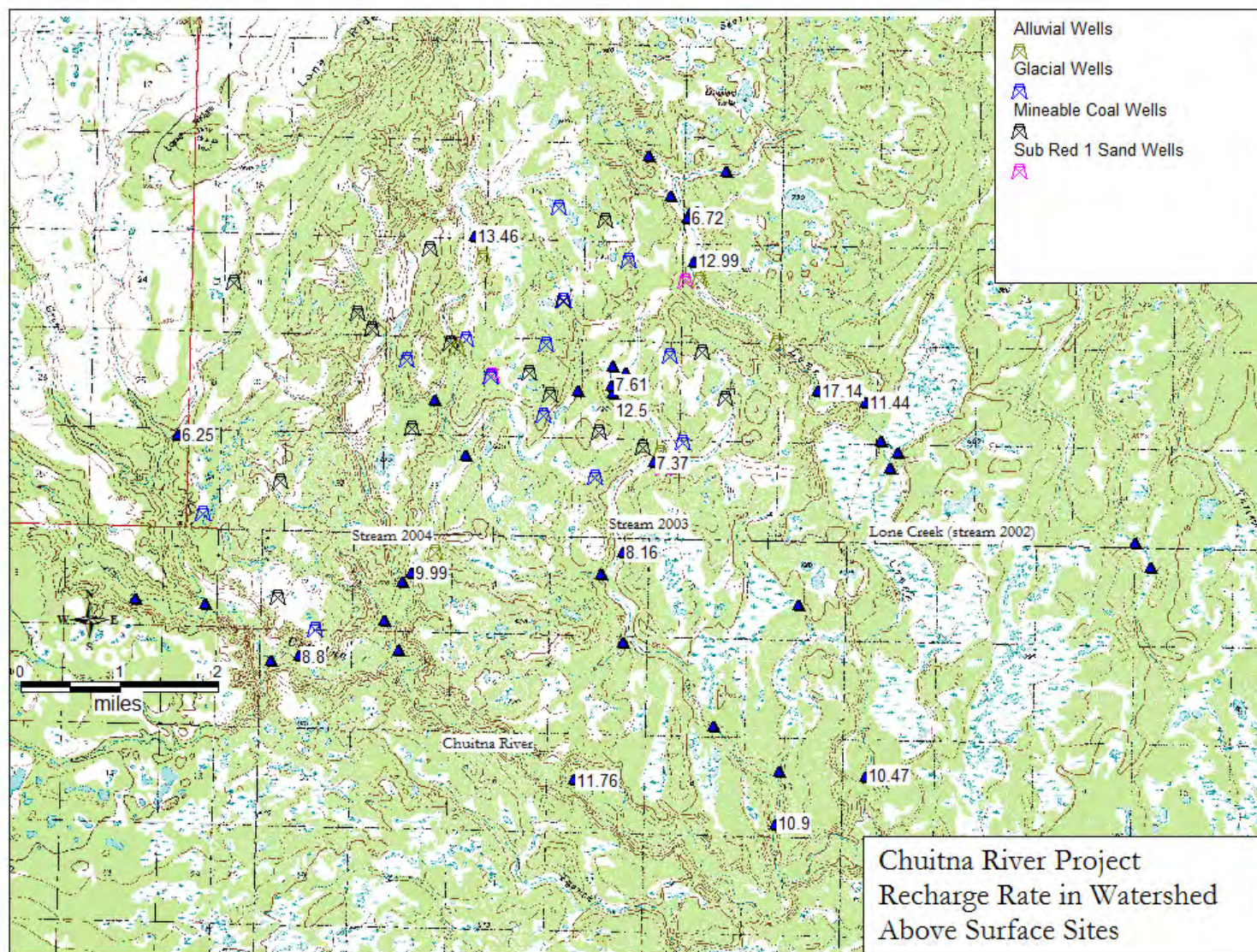


Figure 10: Baseflow Yield in the study site around the Chuitna River basin. See Figure * for the monitoring site names.

Discharge to Streams

Both channels 2002 (Lone Creek) and 2004 have multiple inflow and outflow areas (Figures 11 and 12). There is a complicated exchange of water through the hyporheic zone (Oasis, 2010), with water entering and leaving the channels. Based on both temperature readings and head gradients between the stream and near-stream groundwater, Oasis (2010) found a dynamic equilibrium between inflow and outflow. They also found some correlation with landforms, gradients, and other channel features. This complexity contributes to the necessary complex habitat heterogeneity necessary for the maintenance of biodiversity (Palmer et al, 2009). If the groundwater discharging to the alluvium changes in rate, volume, location, or temporally through the year, the discharge patterns to the creeks will also change. Changing the flow pattern to the alluvium will change this dynamic equilibrium. They had considered these micro-differences in an attempt to determine where to augment the stream flow.

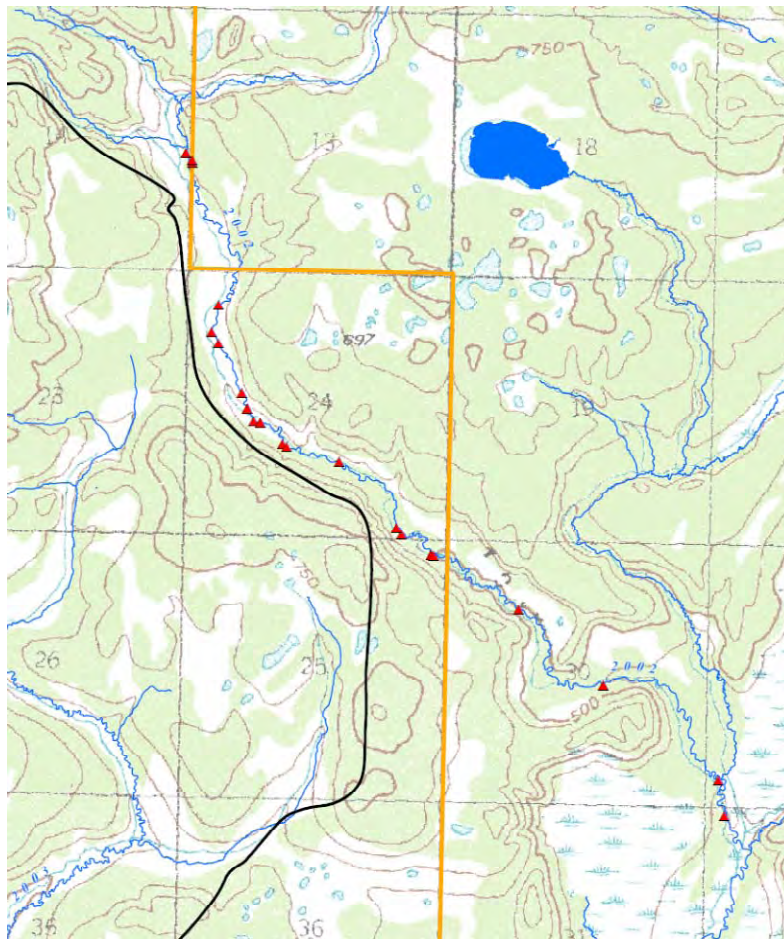


Figure 11: Figure 3.1-9 from Oasis (2010) showing the location of seeps in stream 2002 based on temperature measurements.

Wetlands

Wetlands are physical features on the landscape that also have important hydrologic functions in regulating runoff and groundwater recharge and discharge (Bullock and Acreman, 2003; Winter, 1998);

the three hydrologic functions are intimately connected. Their function depends significantly on their location in the landscape (Figure 13). Wetlands that occur in valley lowlands and at toe slopes were considered discharge wetlands (HDR, 2008, section 3.2.4) whereas isolated wetlands on flat uplands were considered as recharge wetlands (HDR, 2008, section 3.2.5). An assumption apparently is that discharge to wetlands eventually becomes streamflow, but the mine studies are unclear about that (HDR, 2009). Wetlands on the floodplains or otherwise near the streams are not likely to be isolated, therefore assuming wetland discharge becomes stream discharge is justified. Evapotranspiration (ET) losses from wetland vegetation would draw from that discharge and represent a depletion of groundwater recharge before it becomes discharge. ET is not a factor during the winter when groundwater-sustained baseflow discharge is essential.

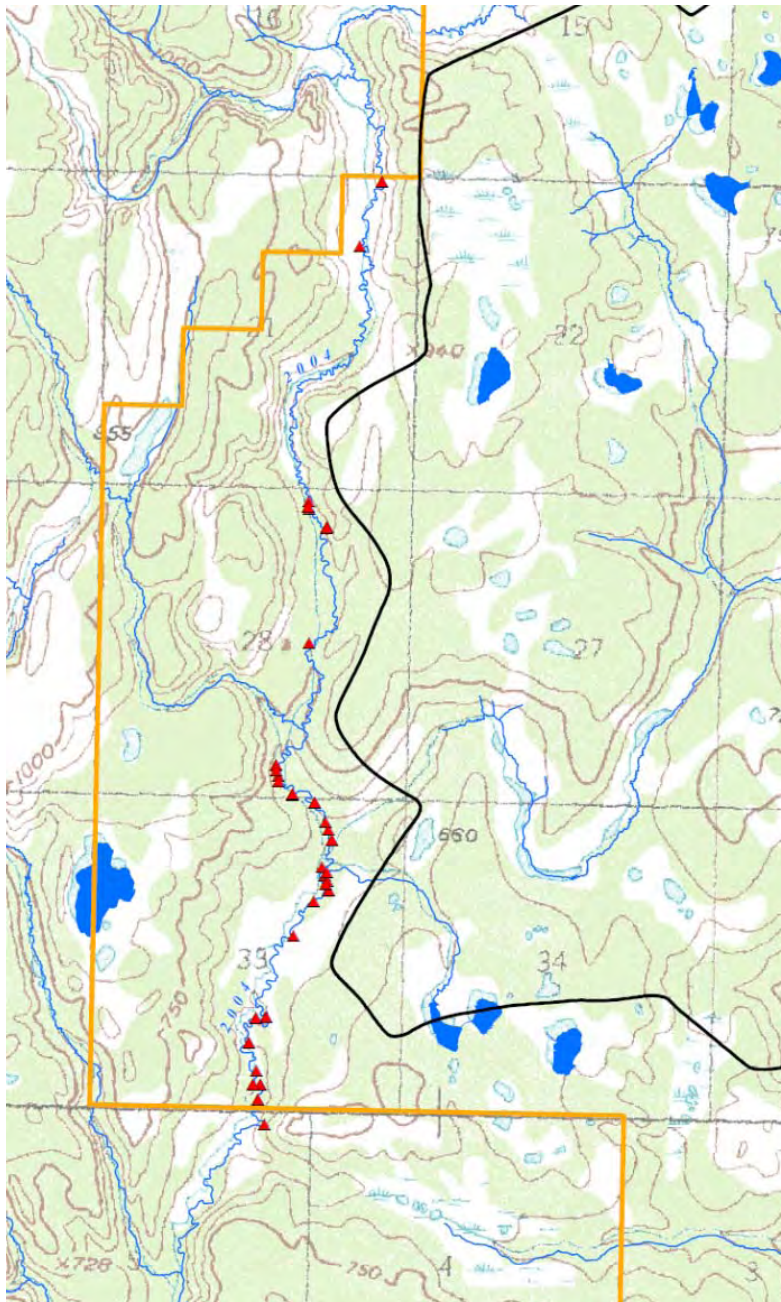


Figure 12: Figure 3.1-10 from Oasis (2010) showing seeps along stream 2004.

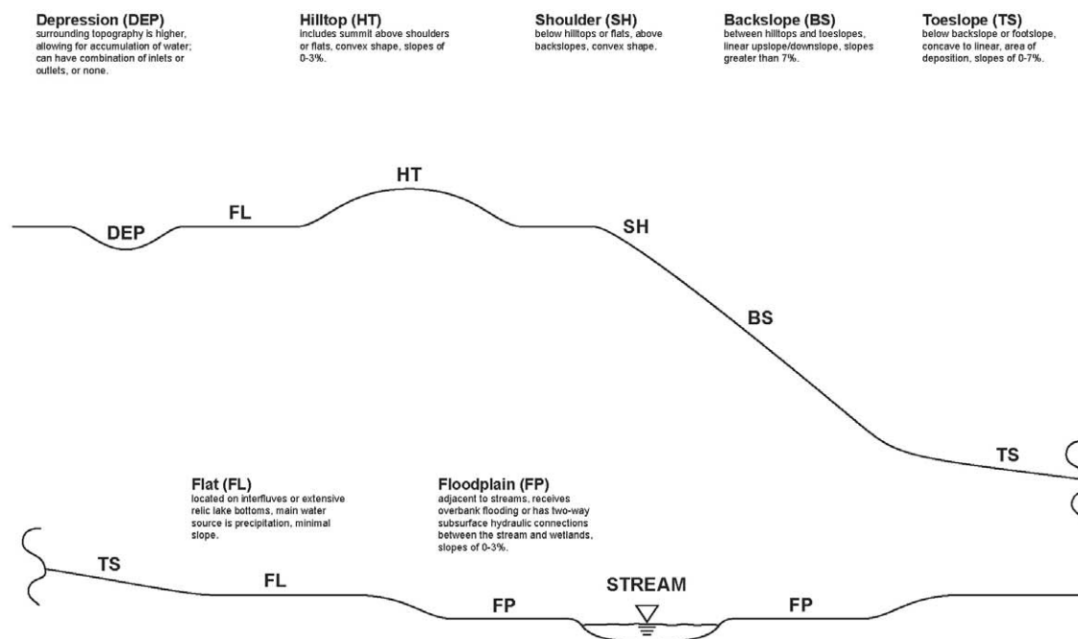


Figure 13: Figure 4 snapped from HDR (2009) showing landform patterns for classifying wetlands.

Floodplain wetlands are most important for regulating runoff because wetlands help store overbank flows and slow its return to the streams, which occurs either by runoff or interflow. They may not regulate baseflow during winter because the pathways – overland flow through wetland vegetation and shallow groundwater inflow – would be frozen. Floodplain wetlands may likely also be discharge wetlands. They may also be recharge wetlands to the alluvial aquifer, although the area of such wetland is likely very small based on wetland function proportions (HDR, 2008). Wetlands on floodplain discharge sites may receive discharge from the alluvium which originated as recharge in the glacial drift or mineable coal sequence. The focus of this study is on the recharge and discharge functions because they are most difficult to account for and to restore.

By far, the discharge dominates the wetland functions at the Chuitna Coal Mine site (HDR, 2009), with 42% of the wetlands (1646 acres) in the proposed mine area contributing this function. Only 1% (24 acres) of the wetland area contributes a recharge function. “Uplands are expected to recharge groundwater at a higher rate than wetlands, with wetlands contributing to groundwater recharge only when they are isolated from streams and found in flat landforms” (HDR, 2009, p. 23). The premise is that free-draining uplands should allow more recharge than wetlands that are not isolated and flat; this implies therefore that the recharge rate on the uplands is higher than an overall average rate because non- or slow-recharging wetlands would not contribute. This is similar to the findings of Bullock and Acreman (2003) that many headwater wetlands actually slow the recharge because they exist due to the fact that the underlying formation has low vertical conductivity. The statement by HDR is justified.

Mine proponents evaluate post-mining wetland functions by demonstrating that their grading and revegetation plans would reestablish the same amount of wetland function, based on vegetation and slope

type (HDR, 2009, p. 3). They acknowledge that successful restoration is critical: “A critical underlying premise of this analysis is that the plans for restoration of post-mining topography, hydrologic features and characteristics, and establishment of vegetation are successfully implemented” (HDR, 2009, p. 1). Their assessment of the potential reclamation of the proposed mine site is analysis of “a hypothetical scenario of the geographic pattern of reclamation wetland communities” (HDR, 2009, p. 4). For the analysis of post-mining conditions, “scientists draped vegetation communities over the post-mining landforms in proportions and patterns similar to those found in the baseline condition” (HDR, 2009, p. 17). The “draping” was a hypothetical GIS exercise that assumes they will successfully restore the wetlands just as they existed prior to mining. Apparently, mine proponents assume that wetland function at a point can be restored and then extrapolate that assumption to the whole mine site. Using GIS, they argue the recharge function will be the same as existed prior to mining.

Assumptions that the wetlands can just be recreated are fallacious without evidence proving it can be done. The National Academy of Sciences (NAS) (2001, p. 25-27) concluded that vernal pools, fens, and bogs were the most difficult to restore. All three of these types describe the wetland systems present in the Chuitna watershed, but bog may be most accurate. Bogs occur on peat soil which requires millennia to establish. As described, wetlands are much more than a recharge or discharge point for groundwater, and the findings of the NAS indicate that this aspect of mine reclamation will likely fail. Unlike most of the studies where restoration consists of rewatering a dewatered wetland or minor recontouring, restoration from surface coal mining where the wetlands are part of the overburden, such as in the Chuitna watershed, involves creating the wetland from scratch and has not proven possible in the past.

Hydrogeologic Properties of the Formations

Most recharge enters the system through the glacial drift. Much of the discharge is from the glacial till to the alluvium to the river/tributaries. The glacial drift ranges from 40 to 140 feet thick with measured conductivity from 10 to 300 ft/d (Arcadis, 2007, p.4). (Their Table 3 shows “K observed” ranging from 0.05 -330.0 ft/d.) Arcadis calibrated three glacial drift model zones to have horizontal conductivity equal to 1.5, 8.0, and 50.0 ft/d, respectively, and vertical conductivity equal to 0.15, 0.16, and 1.0 ft/d. Unfortunately, there are no measurements with which to compare the vertical conductivity. Based on my modeling experience, the relatively high calibrated vertical anisotropy³ was required to match the observed mounds in the water table. Lower horizontal conductivity would also cause the mounding but the saturated thickness decreases near the points of discharge so that the lower conductivity may have made calibrating the appropriate discharge more difficult.

The alluvium is up to 40 feet thick (Arcadis, 2007, p. 4) and therefore stores substantial amounts of water before it reaches the river; Arcadis estimates the conductivity would range from 30 to 300 ft/d, based solely on grain size distribution (*Id.*). Based on percolation tests, Arcadis (2007, Table 3) noted that observed conductivity is 0.25 to 4.22 ft/d. Their calibrated values for two model zones were 300 and 20 ft/d, much higher than the percolation tests. This is not unexpected because of scale issues; a percolation test is a point measurement whereas model calibration is over a larger area which usually has larger

³ Vertical anisotropy is the ratio of the horizontal to vertical hydraulic conductivity. Very low values indicate the horizontal conductivity is much higher than the vertical, which means little vertical flow will occur through the formation.

conductivity (Schulze-Makuch et al, 1999). Large-scale conductivity is often much higher than point measurements when the aquifer is highly heterogeneous.

Arcadis reported the observed horizontal conductivity for the mineable coal sequence ranges from 0.00028 to 14 ft/d, a huge range, and calibrated it to equal 0.01 with the vertical conductivity equal to 0.0009. The low vertical anisotropy is due to the conceptualization that most of the recharge ends up in the glacial drift with little vertical movement to lower layers. The low vertical conductivity backs up the infiltrating water, preventing much of it from entering the mineable coal, so that it flows horizontally through the glacial drift to the streams and alluvium. The relatively high horizontal conductivity allows for through-flow from west to east of the study site, with some discharging into Lone Creek. Both conductivity magnitudes are similar to that found for the coal/sandstone sequences by Myers (2009).

Above I estimated that 2.3 cfs (198,720 ft³/d) discharged from the mineable coal to the Lone Creek alluvium and eventually to the creek. The width between gages would be about 2 miles, so the flow cross-section would be 2 miles times the effective aquifer thickness, or 2*5280*t, or 10,560t ft³. In the mineable coal, Riverside (2010, p. 4-23) indicated the gradient is flatter on the west and increases to the east (.015 to .19 ft/ft). Applying the higher value, transmissivity, T, would equal (198,720/(10,560*.19)), or 99 ft²/d. For a cross-sectional thickness varying from 10 to 100 ft (it is unknown without further analysis), the conductivity varies from 0.99 to 9.9 ft/d. This is well within the reported measured range but much higher than Arcadis' calibrated value.

The observed conductivity in the sub red 1 sand ranges from 1.8 to 8.0 ft/d (Arcadis, 2007, Table 3), which indicates it could pass significant amounts of flow. They calibrated it in two zones as 1.0 and 20.0 ft/d, but the vertical conductivity is extremely low, at 0.00002 ft/d. This low value prevents the recharge on the site from sinking into the deeper layers but allows most any amount to pass through from west to east without discharging to the creeks. Because this layer would likely not be disturbed by mining, the accuracy of the estimate does not have much significance to the conceptual model for the site.

The gradient between “upgradient well (27G1U) and down gradient well (24D2) is 0.013” (Riverside, 2010, p. 4-21). Used with transmissivity (300 to 1800 gpd/ft, p. 4-4), the flow could range from 211,000 to 1,270,000 ft³/d over a mile wide section of the red sands aquifer (1774 to 10,640 af/y).

Groundwater Quality

The analysis here deals primarily with flows and the ability to reconstruct those flows, not the groundwater water quality. However, most analysis suggests the groundwater is mostly compartmentalized with little water seeping from the glacial drift to the mineable coal. If so, there could be differences in the groundwater type among aquifers.

Based on chemistry reported in Riverside (2010), all formations are of the calcium bicarbonate type, with slightly less calcium in the sub red 1 sand. Although this does not prove the groundwater mixes among aquifers, it suggests the source of the glacial drift and alluvium is the same as that of the mineable coal. This could result from the erosion, both fluvial and glacial, of the Tyonek formation providing the source material for the drift and alluvium.

The mineable coal sequence groundwater exceeds aquatic life, and occasionally drinking water, standards much more often than does the groundwater in the glacial drift. The parameters commonly exceeded by minable coal groundwater include aluminum, arsenic (drinking water standard), cadmium, copper, iron, lead, manganese, nickel, silver, and zinc (Riverside, 2010, Table 5-20) while the groundwater in the glacial drift exceeds standards for iron, lead, manganese, and silver (Riverside, 2010, Table 5-14). It is probably not possible to distinguish the source of the contamination between the coal and the interburden, but backfilling the overburden would likely increase the contaminant load. This could occur, at least temporarily, because the previous structure of the interburden would have been broken by the mining process. Baseflow initially after backfill would have higher contaminant levels.

Summary of Conceptual Flow Model

The hydrologic and geologic data reviewed for this study reveal a remarkably diverse and complicated flow pattern affecting baseflow in the study area streams as reflect in the flow and groundwater data for the three mine site area streams – 2002 (Lone Creek), 2003, and 2004 – reviewed in this study. Mining would affect streams differently, depending on whether mining excavates the stream or simply the flowpaths to the stream. Restoration faces many obstacles because the hydrology complexity must be restored in order to restore the baseflow hydrograph, in all of its variability. Mining would also affect the entire Chuitna River baseflow. For example, considering the proposed Chuitna Coal Mine, the three mine site streams produce about 41% of the river's baseflow.

Two groundwater flow systems, the glacial drift and the Tyonek formation, which consists of the mineable coal sequence and the sub red 1 sand, control the baseflow in the study area streams. Inflow to the system is both recharge through the surface, which in the study area is primarily the glacial drift, and flow from offsite west to east across the site through the minable coal and sub red 1 sand. The glacial drift forms a sequence of local aquifers that form groundwater mounds during recharge events and discharge groundwater to nearby streams throughout the year; the recharge replenishes the storage which discharges subsequently to the streams. The mineable coal passes flow from west of the Chuitna River to discharge into stream 2002, Lone Creek, because this creek eroded into the Tyonek formation.

Baseflow depends on recharge rates that vary temporally and across the watershed and heterogeneous properties of the wetlands, soils, and glacial drift. It also depends on a relatively impermeable layer, the minable coal, preventing the recharge from draining too deeply. Additionally, baseflow requires a layer beneath the glacial drift with sufficient transmissivity and connectivity with upstream sources to pass groundwater from offsite to stream 2002. These hydrologic properties control the rate at which the recharge becomes discharge and therefore the rate the baseflow recedes.

The glacial drift is extremely heterogenous. Silt and clay substantially control the conductivity and the ability of an aquifer to hold and release groundwater, but the proportion of silt and clay varies immensely over the study area. This variation, which is mostly random, causes heterogeneity in the hydrologic properties and varying gradients and transmissivity along the flow path. Average properties estimated in groundwater models or found from tests do not begin to replicate the in situ complexities.

Storativity is the amount of water released for a given decrease in the potentiometric surface or water table. Because clay and silt control the size of the pore spaces, and generally the pore spaces control the

rate that water is released from storage, the variable silt and clay proportions indicate that the amount of water released from storage varies significantly around the site. The variable rate that aquifers release water from storage adds further variability to the baseflow recession.

Recharge around the site has been shown to vary by about a factor of two, from about 6 to 13 in/y. However, recharge as determined at a point is an average over all of the small recharge units upstream in the watershed. Recharge at a point depends on the soils, the underlying glacial drift properties, and the presence and type of wetland on the surface. As noted, non-wetland glacial drift likely has much higher recharge because it is free draining. Conversely, isolated wetlands allow recharge, but more slowly because of the low vertical conductivity which prevents them from quickly draining. These wetlands store water on the surface and provide recharge after the free-draining areas have dried. Therefore, recharge rates are actually an agglomeration of highly variable recharge components across the landscape. The thickness and properties of the unsaturated zone beneath the wetlands also control the rate at which water seeping through the ground surface actually reaches the aquifer.

The factors controlling baseflow discharge to the streams are highly variable across the site. The combination of recharge rates that vary around the watershed with variable unsaturated zone properties with variable properties in the glacial drift saturated zone controls the actual baseflow to the streams. Groundwater inflow to the streams has been shown to be highly variable within individual stream reaches and along the stream lengths. It is this complexity along the stream to which the aquatic habitat has adapted (Vannote et al, 1980; Winter, 1998).

This complexity must be restored if the aquatic habitat in the streams affected by mining is to be restored. The immediate effects depend on whether a stream is excavated or is affected in other ways. The proposed Chuitna Coal project would excavate stream 2003 and remove about half of the watershed and glacial drift and minable coal aquifers for stream 2002 and 2004 (Lone Creek). All of the streams in the study area receive baseflow from variable recharge through the heterogeneous glacial drift which would be totally removed by stripping to reach the mineable coal. The mineable coal prevents the recharge from draining vertically away from the glacial drift and provides a significant discharge of water to stream 2002, likely from outside the project area.

Palmer (2009) states that a database which documents over 38,000 restoration projects does not contain a single case in which a rebuilt stream fully compensated for the ecological functions lost when a stream was destroyed. As she noted: “Contrary to suggestions made in the mitigation plans, the very concept of creating streams with levels of ecological function comparable to natural channels on sites that have been mined-through ... remains untested and quite unlikely to succeed” (Palmer, 2009, p.). Even if the stream cross-section can be made to resemble some stream type, the low flow characteristics dependent on heterogeneous groundwater inflows and small-scale water (and nutrient) exchange between the stream and hyporheic zone cannot be restored (Palmer et al, 2009). In the proposed Chuitna Coal Mine project site, the detailed small-scale water exchange documented by Oasis (2010) cannot be restored.

Therefore restoration must replicate several aspects of the existing conditions – the distribution of soils and wetlands across the landscape, the variability in hydrologic properties in the glacial drift, and the relative impermeability to vertical flow present in the coal seams. The baseflow hydrograph in affected streams, not just an average baseflow rate, must be replicated. If the initial rate is too high, the

groundwater storage may drain too quickly so that the rate at the end of the period could be too low to support the aquatic habitat. If the aquifer stores too little water, baseflow throughout the period will be too low. Alternatively, too much recharge or too much groundwater storage would cause the baseflow to be too high which may disrupt the sediment and temperature conditions in the stream. It is essential to replicate both the average and range in baseflow to restore aquatic habitat. Because of the variable recharge and heterogeneous aquifers which must be restored to replicate the baseflow, it is not possible that a mine site can be restored so that the habitat which is dependent on the baseflow can be similar to its pre-mine value.

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