Annotated Bibliography:
Potential Impacts of Energy Development on Fisheries in the Rocky Mountain West

Prepared for:
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Introduction

Public lands in the Rocky Mountain west provide anglers with limitless fishing opportunities and are essential to the cultural, social, and economic framework of the region. According to the U.S. Fish and Wildlife Service's 2001 National Survey of Fishing, Hunting and Wildlife-Associated Recreation, nearly 2.5 million anglers each year benefit from the natural resources found in this region. Through license fees, equipment purchases, and other related expenditures, anglers contribute approximately $1.7 billion to the region's economy each year.

This area is also abundantly rich in natural resources which are available for a variety of energy development practices. Extracting these natural resources requires an extensive and pervasive infrastructure of roads, pipelines, well pads, and transmission corridors that significantly alter the landscape of the region. In addition, the de-watering of coal seams and the disposal of wastewater as well as runoff and pollution from industry infrastructure and spills, places increased pressure and stress on sensitive aquatic ecosystems. Without proper planning, the cumulative effects of ongoing development may drastically alter the ability of the landscape to adapt to these processes.

Oil and Gas Exploration and Development

In response to growing concerns of energy self-sufficiency and issues of national security, there has been a dramatic increase of oil and gas exploration and development on public lands throughout the Rocky Mountain west. Energy resource development is taking place regardless of the impacts that anthropogenic disturbances have on already susceptible aquatic resources throughout the region. However, there is an awareness that certain land-use activities have negative and lasting impacts on aquatic ecosystems. A thorough understanding of the effects that energy exploration and development has on the region's aquatic resources should serve to improve the decision making process which will ultimately prevent, minimize, or mitigate the impacts on fishery resources while also balancing the need for proper and adequate energy development processes.

Due to the rapid pace of energy resource exploration and development, natural resource managers have not had the opportunity to react as quickly as needed to the impacts on the environment and adequately address all of the issues involved. Studies are currently underway to examine the potential long-term effects associated with different types of energy development, but the pace of development continues to increase.

There are two managerial problems that arise from the rapid pace of energy development on our public lands:

- Before steps can be taken to prevent or minimize impacts, the burden of determining what impacts development will ultimately have on aquatic resources in the region rests entirely on resource managers.
- In many cases impacts are not immediate, but rather are noted as the quality of fishery resources gradually diminishes over time.

In order to prevent losses to both fisheries and the affected local economies in the region, it is imperative that managers are able to account for the integrity of the regions resources and provide successful methods of maintaining that integrity.

Purpose of the Bibliography

The purpose of this bibliography is to provide a resource to assist fisheries managers making decisions in the face of rapid energy development throughout the Rocky Mountain west. This document attempts to encompass the most recent and historically relevant literature that will serve as a foundation on which to base management decisions, guidelines, and recommendations. There is very little case-specific information readily available on the effects of oil and gas development in the Rocky Mountains, however there is a wealth of information that can be used to identify and prevent or minimize common potential problems before they occur.

This review is divided into three sections addressing the potential impacts of energy development on fisheries resources:

- Effects of landscape disturbances
- Effects of industrial pollutants and by-products
- Habitat and species management and assessment

As development continues and more information is made available concerning the impacts of energy exploration and development, this work will be expanded in order to provide managers with an adaptive tool for the decision making process.

Effects of Landscape Disturbances

-- including information on the effects of roads, sediment, water diversion, barriers, changes in riparian vegetation, temperature, overall hydrology, etc…

Alexander, G.R., and E.A. Hansen. 1977. The effects of sediment from a gas-oil well drilling accident on trout in creeks of the Williamsburg area, Michigan. Lansing, Michigan Dept. of Natural Resources, Fisheries Research Report No. 1851.

This report was put together in response to a gas-oil well drilling accident which caused abnormally large quantities of sediment-laden water to enter trout streams of the Williamsburg, Michigan area. In April of 1973, the drilling of a gas-oil well resulted in uncontrolled natural gas moving up the well shaft then laterally, carrying groundwater and creating small geysers which erupted at the surface. The muddy water discharged from the geysers then flowed into nearby streams. The accident resulted in large increases of both sediment and stream discharge of the affected streams. The objective of this study was to determine the impact of this sedimentation event on trout.

Substantial amounts of data were collected on the affected stream reaches and compared with control reaches throughout the affected area. Sediment data showed that for the affected Williamsburg Creek, the increased sediment discharge over a two week period following the accident was 1,400 tons compared to the estimated normal range of discharge of 5-20 tons for each stream during the same period. Other water quality parameters remained fairly constant suggesting that the water discharged from the geysers originated from local (shallow) groundwater aquifers. Based upon the trends for the control areas it was concluded that fall trout populations decreased an estimated 48-59% following the accident and the spring populations were lowered some 55-62%. The potential for accidents such as these to affect streams could be detrimental to local fisheries and should be taken into strong consideration when monitoring impacts from oil and gas development.

Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. Ecology 69(2): 382-392.

This study was conducted to monitor the effects of artificial disturbances on structure and function of natural biological systems. Fish community structure and habitat relationships were compared in two rivers: one with artificial short-term flow fluctuations and one with a natural flow regime. The comparison was made on the basis of fish densities by species and habitat guilds to identify the differences among stream fish densities that accounted for both the direct effects of flow variability (i.e. habitat variability) and the way different fish used stream habitat.

The results of the study indicated that extreme flow variability acts to impose functional habitat homogeneity. Fluctuating habitat conditions reduced and eliminated slow and shallow microhabitat guilds indicating that that this group was not able to persist in its particular microhabitat even though that microhabitat always physically existed. Without the functional availability of certain habitat conditions the stream can become dominated by a few habitat generalists. It was noted that disturbances of natural magnitudes that occur at naturally high frequencies can exceed the ability of most species to exploit the variability, thus reducing functional habitat heterogeneity and community complexity. This should be taken into account when redirecting or discharging water into stream ecosystems.

Barrett, J.C., G.D. Grossman, and J. Rosenfeld. 1992. Turbidity- induced changes in reactive distance of rainbow trout. Transactions of the American Fisheries Society 121:437-443.

The purpose of this study was to examine the effects of turbidity on foraging by wild rainbow trout (*Oncorhynchus mykiss*). The research was conducted in a controlled stream environment with captured fish which were fed prey items at increasing levels of turbidity. Foraging behavior was documented in terms of reactive distance and pursuit speed.

Foraging success was tested at three levels of turbidity; ambient (4-6 NTU's), low (14-16 NTU's), and high (29-31 NTU's). It was determined that turbidity had a consistent and strong negative effect on reactive distance. Even low increases in turbidity (9-11 NTU's) were sufficient to significantly reduce reactive distance of rainbow trout. In general, increases from ambient levels of turbidity, reduced reactive distance approximately 20%, or about a 2% reduction per unit increase in turbidity. Similarly, reactive distances at 30 NTU's were reduced approximately 55% from values at ambient turbidity or a 2.2% reduction per unit

increase in turbidity. The data represents approximately a 35% decline in reactive distance from 15-30 NTU's.

The results clearly indicate that wild rainbow trout exposed to increasing levels of suspended sediment are subject to reductions in their ability to detect prey. This in turn may lead to reduced prey capture rates and foraging success, lowering the growth and fitness of the fish. The conclusions of this study should be taken into strong consideration when planning for roads and other sources of anthropogenic disturbances which can produce substantial inputs of sediments to stream ecosystems.

Baxter, C.V., C.A. Frissell, and F.R. Hauer. 1999. Geomorphology, logging roads, and the distribution of bull trout spawning in a forested river basin: Implications for management and conservation. Transactions of the American Fisheries Society 128:854-867.

This study investigated spatial and temporal variations in bull trout (*Salvelinus confluentus*) redd numbers with respect to landscape geomorphology and land-use activity among nine principal spawning tributaries of the Swan River, Montana. The authors also examined trends in redd counts and assessed the current design for monitoring bull trout populations in the Swan Basin, in the context of geomorphic and land-use status.

The authors examined nine tributary drainages supporting substantial bull trout spawning runs for landscape-scale geomorphic characteristics and land-use histories that might effect redd density and distribution. Data was taken from three previous basin-wide surveys to help analyze redd count trends. Results of this study show that changes in redd numbers with time were negatively correlated with catchment and road density and positively correlated with the extent of bounded alluvial valley segments. The authors state that land use, particularly catchment road density has a negative effect on bull trout spawning populations. Furthermore, that prior land use has adversely affected local population abundance in the drainage.

The authors suggest that protection of critical spawning tributary catchments from additional road building and associated land-use disturbances is essential to the maintenance of viable bull trout populations. The authors also suggested that more direct measures of fry growth and juvenile survival along with redd counts would be beneficial in monitoring the status and trends of populations as related to land-use within the region to account for physical and biological lags between disturbance, habitat change, and perceived responses.

Belford, D.A., and W.R. Gould. 1989. An evaluation of trout passage through six highway culverts in Montana. North American Journal of Fisheries Management 9: 437-445.

This particular research focused on fish passage through culverts. The objective of this study was to measure the combinations of water velocity and distance that could be negotiated by brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), and cutthroat trout (*O. clarki*). It was conducted in order to gain useful information for designing new culverts and for identifying existing culverts that prevent or limit the passage of non-anadromous salmonids.

This study was done on six round, corrugated-metal culverts at four sites in Montana. Trout passage through culverts was determined through seasonal spawning periods. Hydraulic characteristics and strenuous conditions of trout passage were taken into account as field testing was conducted. Results showed that for maximum passage lengths of 10, 30, 50, 70, and 90m, maximum velocities that permit passage for non-anadromous salmonids are 1.32, 1.12, 1.04, 0.99, and 0.95m/s respectively.

The authors note that culverts with high velocity waters continue to impede or depress habitat availability and spawning migrations and therefore recruitment. As a result it was recommended that the aforementioned results be used as maximum allowable bottom velocities for passage lengths in culverts. The findings should be taken into account when culverts must be used for roads crossing streams in project areas.

Dunham, J.A., B. Rieman and G. Chandler. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. North American Journal of Fisheries Management 23: 894-904.

This was a comprehensive field assessment of bull trout (*Salvelinus confluenus*) thermal habitat associations throughout the southern margin of the species' range. The authors examined the distribution of bull trout within streams by relating patterns of occurrence to a number of important environmental variables, with a focus on maximum water temperatures. The objectives of the study were to 1) determine whether temperature can predict the distribution of bull trout; 2) examine the generality of model predictions from different data sets; and 3) examine the influence of other environmental variables on the distribution of bull trout.

Sampling was conducted in natural environments throughout the range of bull trout and data was compiled and analyzed. Results of the study show that water temperature is important for small bull trout and that the effect of water temperature on the distribution of this species is relatively consistent across the southern margin of its range. Studies show that when bull trout are exposed to temperatures of > 26°C, mortality occurs in less than 24 h. Results also show that the probability of occurrence at this temperature is relatively low and does not increase until maximum daily temperatures decline to approximately 11-12°C. The authors suggest management actions that would target restoration of the total range of habitats that bull trout might use (e.g. < 26°C) or restoration of water temperatures that bull trout are more likely to use (e.g. $\leq$ 12°C). This work shows that large, isolated, and undisturbed coldwater habitats are more likely to support local populations of bull trout. It is noted that conservation efforts would be much more beneficial if existing areas with these characteristics were identified, along with where restoration could provide these conditions.

Eaglin, G.S., and W.A. Hubert. 1993. Management briefs: Effects of logging and roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming. North American Journal of Fisheries Management 13: 844-846.

The purpose of this study was to examine the influences of land surface disturbances such as logging and road building on substrate and standing stocks of trout (*Salvelinus* and *Salmo*). The authors monitored substrate and trout abundance of different stream reaches in the Medicine Bow National Forest, Wyoming.

The results of this study showed that three measures of substrate were significantly related to the density of culverts. Also, that the extent of embeddedness and the amount of fine sediment increased, and the amount of cobble decreased as the amount of roads which crossed waterways increased. As sediment delivery into streams increased, standing stock of trout decreased. The authors suggested that managers should direct more attention to the design and layout of roads in order to reduce impacts on stream habitat and fishery resources. This study explicitly shows the relationship that increased runoff and erosion from landscape surface disturbances can have on a watershed and the fishery resource.

Gibson, R.J., R.L. Haedrich, and C.M. Wernerheim. 2005. Loss of fish habitat as a consequence of inappropriately constructed stream crossings. Fisheries 30(1): 10-17.

This study was conducted to determine the extent to which stream crossings along a newly constructed section of the Trans Labrador Highway (TLH) accorded with government regulations for fish habitat protection. Objectives were to: 1) ascertain if fish movements or habitat may have been changed by the new sections of the TLH, and 2) to assess compliance with section 35 of the Canadian Fisheries Act, which stipulates that there be "no net loss of the productive fish habitat resulting from any project developments or activities that have potential negative impacts on fish habitat." The authors hypothesized that all crossings would be designed and set in accordance with government guidelines.

Crossings of permanent streams over a 210km section of road, containing 4 bridges and 47 culverts were surveyed for the purpose of this report. Results showed that 53% of culverts posed problems to fish passage because of poor design or installation. The authors estimated that poor installation resulted in loss of 3,001m2 of benthic stream habitat from the culverts themselves. Major problems included insufficient

depth, dry culverts with water flowing under or around, drops at outlets, high velocities impeding passage, and barriers.

The authors hypothesis that all culverts would follow guidelines was proved incorrect. Poor installation resulted in loss of stream habitat and probable consequent loss of upstream rearing habitats. The authors provided several recommendations and cite numerous studies for scientific backing. They concluded that more than half of the stream crossings in their sample had substantially deleterious effects on salmonid migration and habitat and that environmental concerns are frequently ignored or neglected as a result of cost considerations.

Gunderson, D.R. 1968. Floodplain use related to stream morphology and fish populations. The Journal of Wildlife Management. 32(3): 507-514.

The objective of this study was to compare the stream morphology, bank cover, and fish populations of two areas – one where floodplain vegetation was reduced by clearing and grazing and the other where the vegetation was relatively unaltered. This study took place on two contiguous floodplain sections on Rock Creek which originates in the Beartooth Mountains of Montana and Wyoming.

For the purpose of the study stream channels were classified as well as cover and fish populations in both the altered and unaltered stream sections. The results of this study indicated that the weight per acre of brown trout (*Salmo trutta*) was 31% higher in the unaltered stream section. It was noted that this was attributed to there being a narrower, deeper channel system, more favorable composition and distribution of water types and more cover in the unaltered section because the riparian vegetation had been preserved. The number and weight per acre of brown trout in the study greater than 6 in. was 27% and 44% higher, respectively, in the unaltered section of stream.

This study explicitly shows how altered habitat conditions can affect fish productivity. Any activity which will potentially affect streamside (riparian) vegetation has the potential to significantly degrade fish abundance and production. Adequate distancing between land-surface disturbances and water surfaces should be allowed when considering land use.

Harvey, B.C., R.J. Nakamoto, and J.L. White. 2006. Reduced streamflow lowers dry-season growth of rainbow trout in a small stream. Transactions of the American Fisheries Society 135:998-1005.

This study was conducted in response to the variety of resource management activities that can affect surface discharges in small streams. The objective of this study was to measure the effect of streamflow on the survival and growth of rainbow trout (*Oncorhynchus mykiss*) by use of a manipulative field experiment that reduced the influence of confounding variables.

Studies were conducted over a six week period in which inflow of water was reduced 75-80% in four manipulated areas. Flow diversion substantially decreased water velocity in riffle-pool transition areas but did not strongly affect other variables. Results of the study showed that mean relative growth in control units exceeded growth in diverted units by about 8.5 times, while the difference adjusted for the effect of the pool head width was 10.6 times.

This experiment shows that reduced discharge significantly lowered rainbow trout growth in a small stream, suggesting that changes in streamflow with only small changes in other aspects of physical habitat can lead to substantial negative changes in productivity in salmonid fish. The authors suggest that resource managers dealing with the maintenance of salmonid populations in small streams, should give streamflow just as much attention as other potential habitat limiting factors.

Kaeding, L. R. 1996. Summer use of coolwater tributaries of a geothermally heated stream by rainbow and brown trout, Oncorhynchus mykiss and Salmo trutta. American Midland Naturalist 135(2): 283-292.

This study was conducted in the Firehole River, Yellowstone National Park, Wyoming, with the objective of determining how the use of two coolwater tributaries by rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) is affected by the Firehole River temperatures during the summer. The Firehole River receives substantial amounts of geothermally heated, mineralized water from hot streams and geysers. These naturally occurring processes give insight on how fish react to temperature changes within a stream.

Temperatures were recorded hourly at given locations throughout the duration of the study and fish counts were made throughout different stream reaches to determine movements between the Firehole River and the two coolwater tributaries. Results of the study showed that summer use of the two coolwater tributaries by rainbow and brown trout increased exponentially with temperature in the Firehole River. The author points out that as a river warms, use of coolwater tributaries will increase, along with agonistic behaviors, predation, diseases and competition for food among fish in tributaries. It should also be noted that if non-native trout species are displaced into tributaries because of elevated stream temperatures potential for native population declines is more likely because of increased competition for common resources.

McCaffery, M., T.A. Switalski, and L. Eby. 2007. Effects of road decommissioning on stream habitat characteristics in the South Fork Flathead River, Montana. Transactions of the American Fisheries Society 136: 553-561.

This study examined the relationships between the percentage of fine sediment in stream substrate and roads and looked at whether decommissioning had measurable effects on stream habitat in the Flathead National Forest, Montana. Two questions were addressed for the purpose of this study; 1) is there a relationship between substrate composition (percentage of fine sediment) and road density? 2) if so, does road decommissioning have measurable effects on the percentage of fine sediment and other stream habitat characteristics that are important to fish?

Streams in the Flathead National Forest of three treatment types were evaluated in this study: 1) roadless watersheds; 2) watersheds with main roads still in public use but often with spurs that are decommissioned, gated, or both; and 3) watersheds with decommissioned roads (bermed and culverts removed). Watershed treatments were characterized and evaluated and sampling was conducted to quantify the influences that roads had on a watershed.

Results showed that watersheds with higher total road density, roads in use, and road-stream crossings exhibited higher percentages of fine sediment compared with those watersheds that had lower levels of road influence. Also found upon examination was the fact that the most heavily trafficked road exhibited the highest composition of fine sediment. Lastly, it was determined that as decommissioned roads become revegetated over time, the amount of fine sediment loading is reduced to the levels that existed before the roads were built. It should be noted that when planning roads for development projects, careful placement and decommissioning should be taken into great consideration in order to minimize and/or mitigate adverse impacts to aquatic systems.

McIntosh, B.A., J.R. Sedell, R.F. Thurow, S.E. Clarke, and G.L. Chandler. 2000. Historical changes in pool habitats in the Columbia River Basin. Ecological Applications. 10(5): 1478-1496.

This report studied historical changes in pool frequencies and habitat complexity as a result of land use history. Objectives of this study were, 1) to quantify trends in pool frequency and depth in the Columbia River Basin since the earliest surveys; 2) to compare trends across streams of different management emphasis, ownership, and ecoregions; 3) to characterize, and quantify, where possible, the disturbance history in the basin; and 4) to identify potential casual mechanisms between disturbance history and trends in pools.

Streams were classified as natural or commodity based on their watershed management and land use histories. Natural streams were in watersheds minimally affected by human activities with <12% having roads in riparian areas and commodity streams were defined as having watersheds managed predominantly for extraction of resources with roads in riparian areas being about 90%. Stream surveys were conducted and compared with the earliest recorded surveys which were conducted from 1934-1945. Results showed a significant decrease in habitat complexity among commodity streams throughout the basin, while natural streams remained relatively unchanged as far as quantity and quality of pools.

The results of this study support the idea that management and land allocation within a watershed is critical to the protection and restoration of aquatic ecosystems. The capability of streams in commodity watersheds to support fish is severely reduced. A number of factors which are products of development act cumulatively to simplify or alter stream habitats and therefore fish diversity. The authors state that past practices already limit the function and integrity of existing watersheds and that today's managers must manage for today's needs while also correcting the mistakes of the past. It was also stated that there may be a lag time between human activities and detectable effects on watersheds that appear to be supporting high-integrity habitats. The authors conclude that the best opportunity to slow the decline of complex aquatic habitats in the short term may be on public lands through sound management.

McMichael, G.A., and C.M. Kaya. 1991. Relations among stream temperature, angling success for rainbow trout and brown trout, and fisherman satisfaction. North American Journal of Fisheries Management 11:190-199

This study was conducted to determine a relationship between stream temperature and angler success. The specific objectives of the study were 1) to determine whether there was a relationship between elevated water temperature and reduced angler catch rates for rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), and if there was a relationship, 2) to identify temperatures above which catch rates declined to levels that anglers considered unsatisfactory.

Catch rates and fisherman satisfaction were assessed through direct, on-site creel surveys conducted for two years while water temperature was monitored on two sections – an upper, cooler section and a lower, warmer section – of the Madison River in Montana. Results from 1,741 angler contacts showed that as fishing temperatures increased angler success decreased significantly especially in the lower section of the river. The highest percentages of fisherman catching no trout were associated with average temperatures above 19°C.

The results of this study indicate that an increase in stream temperature can have a negative and adverse impact to fishing success. It is noted that relations between temperature and fishing success could have diverse applications in the management of trout fisheries such as creating guidelines in regulating discharge temperatures from impoundments or to evaluate the effects of proposed projects that could elevate stream temperature. The authors suggest that any activity which has the potential to cause streams to be more susceptible to increases in water temperature should be managed so that temperature does not exceed 19°C.

Meisner, J.D., J.S. Rosenfeld, and H.A. Regier. 1988. The role of groundwater in the impact of climate warming on stream salmonines. Fisheries 13(3): 2-8.

This paper reviews the factors that govern the temperature of groundwater and the influence of groundwater on salmonid ecology. The authors show that groundwater has a strong influence on the hydrology and thermal regime of lotic environments. Groundwater provides baseflow and moderates the effect of seasonal air temperature fluctuations. Groundwater discharge acts to maintain necessary cold, headwater communities of streams which are dominated by different salmonid species.

The authors argue that increases in the temperature of groundwater and thus baseflow in a stream can severely impact distribution of trout in a stream. They note that studies have shown strong positive correlations between trout population size and the presence of groundwater in streams. This paper also cites many other studies which show relationships between groundwater and salmonid population structure and biological interactions. It is concluded that if important spawning habitat or stream temperatures are

elevated due to an increase in groundwater temperatures trout populations are highly likely to become displaced and dissipate.

Nelson, F.A. 1986. Flow fluctuations on brown trout in the Beaverhead River, Montana. North American Journal of Fisheries Management 6:551-559.

Effects of variable flow releases from Clark Canyon Reservoir, Montana on standing crops of brown trout (*Salmo trutta*) in the Beaverhead River were studied over a 14 year period. The primary objective of this study was to provide in-stream flow recommendations that enhanced the ability to maintain a high quality fishery resource. Although the study did not meet its primary objective it did provide insights into the relationship between year-class strengths of brown trout and flow characteristics during the spawning period. Changes in flow during spawning periods appeared to have hindered reproduction, thus limiting standing crops of brown trout. It is noted that rapid changes in depth and velocity associated with flow fluctuations interferes with the spawning process thus hindering reproduction and limiting recruitment.

Although this study was unable to prove conclusively that flow fluctuations during spawning were the primary cause of poor yearling crops, it should alert managers to beware of the potential impacts of altered flows on reproducing salmonid populations. The author notes that evaluations should include assessments of recruitment levels following test spills during spawning and a comparison to the norm of the affected waters. The study suggested that reproductive potential of brown trout would be severely limited by such changes in flow regimes. These factors should be taken into consideration when any process occurs that will dewater or directly discharge water into a stream.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11:72-82.

The authors of this paper reviewed available literature in an attempt to identify factors that contribute to effects of suspended sediments on fish and aquatic life. The authors collated and analyzed relevant data in search of a relationship between the magnitude of suspended sediment pollution and severity of effects. These effects were placed into three categories: 1) lethal effects, 2) sublethal effects, and 3) behavioral effects. Subsequently, effects were ranked according to the severity on fish and aquatic life.

The authors compiled the data and summarized the effects of suspended sediment on salmonid fishes, aquatic invertebrates, and periphyton. The report provides tables of effects and rank of effects that resulted in lethal, sublethal, or behavioral responses in different species of the studied fish and aquatic organisms. Also included in this report are numerous references to studies on the effects of sediment on aquatic resources.

The authors concluded that resource managers need information that relates the magnitude of pollution episodes to effects on aquatic ecosystems so the effects of various development schemes can be evaluated. Furthermore, it is stated that research in this field might be better reported in terms of concentration of suspended sediment, duration of exposure, and response so that ability to better predict environmental effects of pollution events might be improved.

Penkal, R.F., and G.R. Phillips. 1984. Construction and operation of oil and gas pipelines. Fisheries 9(3): 6-8.

This particular work is a draft policy statement concerning the environmental effects to fishery resources that result from the construction and operation of oil and gas pipelines. The authors discuss many problems that arise from pipeline projects as well as safeguards to minimize or prevent impacts. Discussion on habitat included adverse effects from channel alteration, sedimentation, accidental spills, fish passage, and ancillary development. The authors also gave a brief overview of the impacts to biota.

This paper also contains plans and recommendations for needed actions concerning the construction of oil and gas pipelines. The authors list four key components which are critical to protecting aquatic resources in light of development. These are planning, education, enforcement, and research. It was concluded that

construction and operation of pipelines can cause significant damage to aquatic habitats and fishery resources, but these impacts can be substantially reduced with the practice of best management. This paper serves as a good reminder to some of the potential effects that occur with development.

Peters, J.C. 1967. Effects on a trout stream of sediment from agricultural practices. The Journal of Wildlife Management. 31(4): 805-812.

This study focused on the effects of sedimentation rates, stream discharge and water temperature in Bluewater Creek, Montana. The author considered the interrelationship between sediment, flow, and water temperature as caused by current irrigation activities and agricultural land-use practices, and how they influence a stream trout population.

Sampling stations were set up along Bluewater Creek so that biological comparison could be made between areas in the stream with little sediment and areas influenced by various degrees of sedimentation. Flow, sediment, water temperature and biological data were all collected and analyzed throughout each section of the stream. Results of the study indicate a negative relationship between amounts of sediment and the trout populations, as sediment increased within sections of the stream, trout populations decreased. Sediment pollution in the stream was accompanied by a decrease in flows and an increase in water temperature. These factors combined to change the environment so that trout were almost eliminated in the lower reaches of the stream.

The author points out that spills which cause periodic fish kills attract a great deal of attention but are, in general, much less harmful than gradual increases in pollution which can slowly decimate a population. It is in this manner that sportfish populations can be destroyed without exciting public interest. Sediment in flowing waters comes from a variety of sources including roads, development, and removal of riparian vegetation. In conclusion, adequate steps should be taken to minimize or eliminate sediment pollution whenever possible.

Shaw, E.A. and J.S. Richardson. 2001. Direct and indirect effects of sediment pulse duration on stream invertebrate assemblages and rainbow trout (*Oncorhynchus mykiss*) growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58: 2213-2221.

The purpose of this study was to address two key questions regarding the biological impacts of fine sediment in lotic ecosystems; 1) determine the effects of fine sediment pulse duration on drifting and benthic invertebrate assemblages and rainbow trout fry growth and mortality, and 2) quantify and compare the direct and indirect effects of sediment exposure on fish growth.

The authors evaluated the effects of sediment pulse duration using 14 streamside flow-through experimental channels, each of which contained a naturally colonized invertebrate assemblage and 10 rainbow trout. Channels were exposed to fine sediment pulses of constant concentration but varied pulse duration (ranging from 0-6 h) every second day over 19 days. Results showed that the duration of a sediment pulse, given a constant concentration, had a negative effect on the richness and abundance of benthic invertebrates and the richness of drifting invertebrates. It was also clearly indicated that a negative relationship exists between fish growth and sediment pulse duration.

This particular study once more shows how any anthropogenic disturbance that increases sediment in a stream has the potential to severely affect fish production as well as the aquatic resources which they rely on for feeding. It should be noted that in any event when fish productivity is reduced it will have a deleterious effect on the sport fishery.

Stearns, M., J.A. Tindall, G. Cronin, M.J. Friedel, and E. Bergquist. 2005. Effects of coal-bed methane discharge on the vegetation and soil ecosystem in the Powder River Basin, Wyoming. Water, Air, and Soil Pollution 168: 33-57.

This study was conducted to assess the effects of coalbed methane (CBM) co-produced discharge waters on the soil and vegetation ecosystem. Data was collected and analyzed to: 1) determine if CBM discharge

waters increase salinity and sodicity in the soils; 2) investigate growth and distribution patterns of native, invasive, and salt-tolerant plant species in relation to soil salinity and sodicity from CBM discharge waters; and 3) extrapolate the results of water chemistry analyses to soil analyses to determine the effect of CBM discharge waters on local systems.

Study plots were divided into two categories; (1) riparian areas upstream from CBM water discharge for reference sites and (2) riparian areas downstream from CBM water discharge for "affected" sites. Soil, sediment, water, and vegetation samples were collected from the study plots and taken to a lab for analysis. Results showed that coalbed methane co-produced waters had a significant impact on local soil and vegetation within the study area by elevating salts and sodium in soils and affecting vegetation composition and density.

It should be noted that any change in riparian vegetation can have significant negative impacts on aquatic ecosystem health and diversity. The authors' state that due to the large amounts of CBM co-produced water, more serious problems can be expected in the next 5-10 years. It was also noted that there is a critical need for adequate monitoring and management of CBM discharge waters.

Sweka, John A., and Kyle J. Hartman. 2001. Influence of turbidity on brook trout reactive distance and foraging success. Transactions of the American Fisheries Society 130: 138-146

This study was designed to determine 1) the effects of turbidity on the reactive distance of brook trout (*Salvelinus fontinalis*), 2) how turbidity affects encounter rates between brook trout and their prey, and 3) how turbidity affects brook trout's foraging success. The research was conducted in a controlled environment testing different groups of brook trout under increasing levels of turbidity to determine reactive responses to prey items.

At turbidity levels ranging from 0 – 40 NTU brook trout were given prey items to test their ability to react to prey. The results showed that increased turbidity (even at the lowest levels) decreased reactive distance significantly in both linear and quadratic model parameters. According to the results, prey density must increase exponentially – and faster than reactive distance decreases to maintain a constant encounter rate between brook trout and prey. As turbidity increased, the probability of reacting to an offered prey item also decreased linearly. What this study shows is that with an increase in turbidity brook trout feeding productivity may be significantly decreased.

This paper also cites many other studies relating different species of fish to their ability to detect and react to prey items with increased turbidity. It should be noted that any activity that leads to increased runoff or suspended sediments and thus turbidity has the potential to affect fish production.

Sweka, John A., and Kyle J. Hartman. 2003. Reduction of reactive distance and foraging success in smallmouth bass, *Micropterus dolomieu*, exposed to elevated turbidity levels. Environmental Biology of Fishes 67:341-347.

This study was conducted in order to determine the effect of turbidity on reactive distance and foraging success of smallmouth bass (*Micropterus dolomieu*). Reactive distances were measured as fish were fed prey items in a controlled environment at increasing levels of turbidity from <5 NTU – 40 NTU. Fish were tested in groups of three so that responses to prey items would be increased by competitiveness. Results showed that reactive distance decreased exponentially with increasing turbidity. The greatest rate of decrease in reactive distance occurred from 0 to approximately 25 NTU.

The authors note that reduction in reactive distance has been linked to decreased prey consumption and subsequent growth. The results clearly showed that even slight increases in turbidity can greatly reduce reactive distance in smallmouth bass. It is recommended that researchers and managers should place just as much concern about the effects of increased sediment loads and resulting turbidity in warmwater systems as in coldwater systems.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14(1) 18-30.

The authors of this paper reviewed the scientific literature on the ecological effects of roads on terrestrial and aquatic communities. The work supported the general conclusion that roads are associated with negative effects on biotic integrity in both terrestrial and aquatic ecosystems. Roads change soil density, temperature, soil water contact, light levels, surface waters, patterns of runoff, and sedimentation, as well as adding heavy metals to the environment.

The authors explained and cited many sources on the effects that roads can have on aquatic communities. These factors included altered development of shorelines, stream channels, floodplains and wetlands. Roads can act as barriers to the movement of fishes and other aquatic organisms and contribute to fragmented populations. Finally, they serve as a source of fine sediments, nutrients, and contaminants to aquatic ecosystems.

The authors' note that road design, management, and restoration need to be carefully tailored to account for the affected ecological processes and aquatic organisms. They continue that it is critical to retain roadless or near-roadless portions of the landscape. It was determined that conservation efforts cannot depend upon unexamined assumptions about the capabilities of site- and species-specific mitigation and remediation measures to reduce the ecological consequences of existing and proposed roads.

Warren Jr., M.L., and M.G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127:637-644.

This study examined the effects on fish movement of four road crossing types with different potentials to alter flows. Fish movement through crossings was determined at spring base and summer low flows in small streams in forested watersheds. The authors asked four specific questions: 1) Does crossing type affect overall, directional, or seasonal fish movement? 2) Is crossing type associated with the diversity of fishes or fish families able to traverse the crossing? 3) Are patterns of fish retention affected by crossings? 4) Is there a relationship between fish movement and water depth and velocity through crossings?

A total of nine crossings on eight streams were selected consisting of four different types of crossings (culvert, open-box, ford, and slab). The authors assessed movement for 21 fish species in seven families across these stream crossings as well as through natural reaches. Results showed that movement of fishes was significantly affected by crossing type. Culvert and slab crossings reduced overall fish movement, and movement of fish families relative to natural reaches. In contrast, movement through open-box and ford crossings generally was comparable with or higher than movement through natural reaches. For slab crossings no movement was detected.

The authors conclude by presenting evidence that increased water velocity through culverts is part of the mechanism by which these crossings restrict fish passage. It is noted that given the importance of certain fishes to migrate across stream reaches, road crossings should be designed to minimize effects on fish movement. Understanding water velocity levels in and among stream crossings may be vital to designing adequate corridors for movement of fishes.

Wesche, T.A., C.M. Goertler, and C.B. Frye. 1987. Contribution of riparian vegetation to trout cover in small streams. North American Journal of Fisheries Management 7:151-153.

This study quantitatively described by means of regression, the relative importance of three cover parameters (overhead bank cover, rubble-boulder-aquatic vegetation areas, and deepwater areas) and two cover models as indicators of trout standing stock in eight small streams in southeast Wyoming. This paper stressed the contribution of riparian vegetation to cover availability.

Results were based on field investigations at 27 study sites on eight montane and foothill streams located in the North Platte River Basin of southeast Wyoming. Brown trout (*Salmo trutta*) were the predominant game fish species present at all sites in the study area. The findings agreed with previous studies that banks

bordering small streams provide the habitat edges or niches needed to maintain high fish populations. Of the variables tested, the amount of overhead bank cover available in small streams predominated by brown trout was noted to have the strongest influence on carrying capacity. It should be noted that any activity which removes this variable from stream habitat has the potential to negatively influence habitat complexity as well as population health.

Effects of Industrial Pollutants and By-Products

-- including information on the effects of toxic chemicals and other pollutants entering aquatic ecosystems

Confluence Consulting, Inc. 2004. Powder River biological survey and implications for coalbed methane development. Report prepared for Powder River Basin Resource Council. Sheridan, Wyoming. 179 pp.

This study was conducted to investigate direct impacts of coalbed methane development on water quality and fisheries. The objectives included; 1) Characterizing baseline conditions prior to full development of coalbed methane operations, 2) to evaluate the potential impacts of existing coalbed methane facilities, and 3) Provide recommendations to promote the sustainable development of coalbed methane.

Fish, macroinvertebrates, and periphyton, were sampled at several sites along the Powder River above and below wastewater discharges within the basin as well as Clear Creek and a tributary, and Piney Creek. The results of the study suggested that coalbed methane development within the basin may be negatively affecting water quality because of the noted difference between compared data from the USGS and study collections. Changes in riparian vegetation as well as the rarity of certain fish species were also noted and tagged as concerns.

This study which focused mainly on warmwater systems provided much insight on evaluating risks involved with coalbed methane development and its impacts to fisheries. The changes and concerns to freshwater ecosystems that were discussed in the report can serve as a baseline for future studies and management concerns. The authors suggest an "adaptive management" approach in future evaluation and management of fisheries in the face of energy development.

Dauble, D.D., S.A. Barraclough, R.M. Bean, and W.E. Fallon. 1983. Chronic effects of coal-liquid dispersions on fathead minnows and rainbow trout. Transactions of the American Fisheries Society 112: 712-719.

The objective of this study was to examine the effects of long-term exposures of coal-liquid, water-soluble fractions (WSF's) on fathead minnows (*Pimphales promelas*) and rainbow trout (*Oncorhynchus mykiss*) under continuous flow-regimes. Fish were monitored under 5 varying levels of WSF concentrations in order to gain information on the effects of long-term exposure.

Phenols constituted 95% of the organic carbon in stock WSF's. Growth of larval fathead minnows was significantly reduced at 0.25 mg/L total phenols as determined by dye photometry. Spawning of adult fathead minnows exposed was inhibited at 1.27 mg/L total phenols and was significantly reduced at 0.62 mg/L. The minimal concentration of WSF that resulted in significant mortality of rainbow trout embryos was time-dependent. No rainbow trout embryos survived 14 days of exposure to $\geq$ 2.98 mg/L total phenols because of egg mortality or premature hatching. Swim-up rainbow trout suffered rapid mortality after 28 days exposure to 0.13 mg/L total phenols; death was partially attributable to clogging of their gills by fungal growth.

Davis, W.N., R.G. Bramblett, and A.V. Zale. 2006. The effects of coalbed natural gas activities on fish assemblages: a review of the literature. Montana Cooperative Fishery Research Unit. Montana State University, Bozeman.

This report serves as an in-depth review of the literature relating to the development of coalbed natural gas (CBNG), as well as a summary of the landscapes on which development is likely to occur and the processes involved. The author gives background information pertaining to the geology, physiography, and hydrology of the Powder River Basin (PRB) where most CBNG development is currently taking place. Also discussed are ground and surface water interactions, fish assemblages, processes of exploration and extraction, disposal of product water, and potential effects of development.

This report includes an extensive literature review, citing many relevant sources pertaining to potential effects of CBNG development. Also included is an extensive study plan for a research project with the goal of determining effects of CBNG development on fish assemblages in streams of the PRB. Objectives for the study are: 1) determining if CBNG development within the drainage area of a stream affects the fish assemblage present, 2) determine if CBNG development in the middle or lower reaches of a stream affects

expected longitudinal distribution patterns of fish assemblages, 3) determine if fish assemblages change immediately after CBNG development in a drainage area, and 4) determine if fish assemblages at specific locations in the PRB are the same as they were prior to CBNG development. This work is expected to be completed in 2007.

DeGrave G.M., R.G. Elder, D.C. Woods, and H.L. Bergman. 1982. Effects of naphthalene and benzene on fathead minnows and rainbow trout. Archives of Environmental Contamination and Toxicology 11: 487-490.

This study used fathead minnows (*Pimephales promelas*) and rainbow trout (*Oncorhynchus mykiss*) in flow-through bioassays to determine the acute toxicity of benzene and naphthalene both of which are constituents of petroleum products, and to determine the embryo-larval effects of naphthalene on fathead minnows.

Results of the study showed that benzene and naphthalene were toxic to both rainbow trout and fathead minnows. Benzene was less toxic than naphthalene and fathead minnows were less sensitive to both pollutants than rainbow trout. Egg hatchability *and* fry length and weight at 30 days were all significantly reduced relative to controls at naphthalene concentrations as low as 0.85mg/L. All fry died in naphthalene levels above 4.38mg/L. The study states that the acute toxicities of naphthalene to freshwater aquatic life are reported by the EPA water quality criteria to range from an LC-50 of 2.3-8.9mg/L and that these criteria should be lowered to 1.6mg/L. It is reported that based upon the no-effect naphthalene concentration, the best estimate of the maximum acceptable toxicant concentration would be >0.45 - <0.85mg/L

This paper also reports that the EPA water quality criteria for acute toxicities of benzene to freshwater species range from 5.3-386mg/L. The author's note that the lower value is based on the 96 h flow-through bioassay results reported in this paper for rainbow trout and that the manner in which values for other species were tested may produce deceptively high values. Maximum no-effect limits of these and other pollutants should be taken into strong consideration when setting regulations for development.

Dickerson, Bobette R., and Gary L. Vinyard. 1999. Effects of high levels of total dissolved solids in Walker Lake, Nevada, on survival and growth of Lahontan cutthroat trout. Transactions of the American Fisheries Society 128: 507-515.

The research in this study was presented in an attempt to assess growth and survival of Lahontan cutthroat trout under current and anticipated concentrations of total dissolved solids (TDS) in Walker Lake, Nevada. Management practices in the Walker River basin had caused a significant increase in the concentration of TDS.

Laboratory experiments were performed to assess the response of Lahontan cutthroat trout under different concentrations of TDS. The results indicated that survival was significantly reduced by exposure to all TDS above control conditions. In general, survival was inversely proportional to the amount of TDS present. Fish exposed to the level of TDS in Walker Lake at the time of the study experienced 25-70% mortality within 7 days.

The authors noted that a major reason for the high amount of TDS in the lake was because of high rates of water diversion and stated that without adequate inflow of freshwater into the lake that 100% mortality within 48 hours of stocking could be expected within 20 years. It should be noted that in order to adequately ensure a sustainable fishery resource, factors which can potentially increase TDS in a watershed should be closely monitored and managed.

Farag, A.M., D.F. Woodward, W. Brumbaugh, J.N. Goldstein, E. MacConnell, C. Hogstrand, and F.T. Barrows. 1999. Dietary effects of metals-contaminated invertebrates from the Coeur d' Alene River, Idaho, on cutthroat trout. Transactions of the American Fisheries Society 128:578-592.

This study was conducted to determine the potential for injury to the cutthroat trout (*Oncorhynchus clarki*) fishery from a combination of trace metals interacting through both aqueous and dietary exposures. The authors investigated how metals in food and water in the Coeur d' Alene (CDA) basin affected survival, growth, and other physiological functions of cutthroat trout.

Benthic macroinvertebrates containing elevated concentrations of metals were collected from the CDA River, Idaho, pasteurized, and fed to cutthroat trout in a laboratory from start of feeding until 90 days posthatch. Invertebrates were also collected from two other sites known to contain elevated concentrations of metals as well as a relatively clean site which were used as a reference diet. Results of the study showed deleterious effects on survival and growth, reduced fitness, reduced feeding activity, as well as a number of histopathological abnormalities.

This study was part of a series of lab experiments in which trout were fed invertebrate diets collected from the contaminated river system in question. The authors note that the results are reproducible over a series of different experiments with different species of trout and between different contaminated rivers. Metals affected the health of trout in all cases. None of these studies showed toxicological responses in fish fed diets collected from reference sites. All studies showed similar endpoints: reduced survival, decreased growth, reduced feeding activity, and histopathological abnormalities. The authors conclude that the risk is greatest for early life stage fish, whose diet is restricted to benthic macroinvertebrates. It was also noted in this report that although the aqueous concentrations of each metal were 4X the chronic water quality criteria established by the U.S. EPA for the protection of aquatic life, they were at or below the concentrations measured in the CDA River which cites a lack of adequate monitoring and protection.

Hansen, J.A., D.F. Woodward, E.E. Little, A.J. DeLonay, and H.L. Bergman. 1999. Behavioral avoidance: possible mechanism for explaining abundance and distribution of trout species in a metal impacted river. Environmental Toxicology and Chemistry 18(2): 313-317.

This study was conducted to determine behavioral avoidance of metal mixtures by rainbow trout (*Oncorhynchus mykiss*) in the Clark Fork River, Montana. Objectives of this study were to measure rainbow trout avoidance responses to metal concentrations typical of the upper Clark Fork River, and to compare these results with previously reported responses by brown trout (*Salmo trutta*) exposed to the same conditions to determine whether behavioral avoidance is a possible mechanism for explaining relative abundance and distribution of these two species within the river.

Rainbow trout were collected and tested in controlled avoidance chambers to multiple variables including avoidance of a wide range of metal mixture concentrations, avoidance of acidity, avoidance of acidity and metals, and the influence of metal acclimation on avoidance responses. Results of the study showed that rainbow trout significantly avoided all metal concentrations tested when the total time in the water was compared between the control response and the metal treatment response. Lowered pH levels also increased avoidance by rainbow trout. After acclimation to metals for 45-days fish significantly avoided higher metal concentrations and significantly preferred clean water.

The authors conclude that fish observed in the Clark Fork River showed that rainbow trout populations can detect and attempt to avoid lethal concentrations of metals resulting from increased input within the drainage. It was noted that populations in the upper portion of the river were severely reduced when compared to reference river reaches with similar geologic and geomorphic characteristics. The authors conclude that although rainbow trout are more sensitive to the tested variables than brown trout, both species abundance and distribution may be determined by metal impacts within a river system.

Holm, J., V. Palace, P. Siwik, G. Sterling, R. Evans, C. Baron, J. Werner, and K. Wauter. 2005. Developmental effects of bioaccumulated selenium in eggs and larvae of two salmonid species. Environmental Toxicology and Chemistry 24 (9): 2373-2381.

This study was conducted to examine the possibility of impaired reproduction in wild rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) due to elevated levels of selenium (Se) in cold, flowing water habitats. Fish from these systems had been found to have concentrations of Se in their tissues that exceeded toxic effect thresholds that had been established for warm-water fishes. The objective of this study was to determine if exposure to elevated levels of Se resulted in teratogenesis in the progeny of two salmonid species.

Spawning rainbow trout and brook trout were collected over three consecutive years (2000-2002) from the northeastern slopes region of Alberta near Jasper, Canada. Spawn from both species were collected from exposure and reference sites. Gametes were fertilized in the laboratory, reared to the swim-up stage, and examined for deformities. Data was then compiled in the laboratory for statistical analysis.

Elevated levels of Se were found in the tissues of both salmonid species captured. The levels of Se in the eggs of fish captured at the high exposure site exceeded the toxic effect threshold of 10µg/g (dry wt.) in eggs. A significant relationship was observed for rainbow trout between the amount of Se in eggs and the incidence of developmental abnormalities, specifically craniofacial defects, skeletal deformities, and edema. These associations approximated exponential functions with probabilities that 15% of the population would be affected between 8.8 – 10.5 µg/g Se of wet egg weight. No significant relationships were established for brook trout. The authors suggested that the significance that Se-induced terata will ultimately have on the natural populations of salmonids requires further examination. However, it should be noted that the negative effects discussed for rainbow trout have the potential to affect fish production and survivability.

Moles, A., S.D. Rice, and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Transactions of the American Fisheries Society 108:408-414.

This study focused on the sensitivity of various life-stages and species of Alaskan freshwater and anadromous fish to benzene and water soluble fractions of crude oil. The purpose of this study was to determine the sensitivity of the eggs, alevins, fry, freshwater residents, and anadromous fishes to water soluble fractions of crude oil and benzene. There were six species of salmonids tested which showed similar sensitivities to these compounds.

Fishes were collected and acclimated to a controlled environment in which they were exposed to increasing concentrations of water-soluble fractions of crude oil and benzene. Results of the study indicated that salmonids were consistently the most sensitive species tested with both the water-soluble fraction of crude oil and benzene. Most deaths occurred within the first 12 hours of exposure. Also, the most sensitive life stage of development to exposed fishes showed to be the development from egg to fry. The egg was the least sensitive, alevin stages were moderately sensitive, and the emergent stage was the most sensitive. It should also be noted that anadromous species which were out-migrants at the time of the study were twice as sensitive as those which were still being tested in freshwater. This is due to additional stresses associated with acclimation. Thus, it becomes evident that fish under already stressful conditions which are exposed to contaminants are much more likely to be negatively affected.

Moles, A., S. Bates, S.D. Rice, and S. Korn. 1981. Reduced growth of Coho salmon fry exposed to two petroleum components, toluene and naphthalene, in fresh water. Transactions of the American Fisheries Society 110:430-436.

This study was aimed at determining how two petroleum components; toluene and naphthalene, affected growth of Coho salmon (*Oncorhynchus kisutch*) in fresh water. Salmon fry were exposed to sub-lethal concentrations of toluene and naphthalene to determine concentrations that inhibited growth after 40 day

exposures. Sub-lethal concentrations that affected growth were related to lethal concentrations by being reported as a percentage of the 96-hour LC50 (the concentration that killed 50% of the fry after 96 hours).

Fry that were exposed to sub-lethal concentrations of toluene or naphthalene for 40 days grew significantly less than unexposed fry. The highest sub-lethal concentrations of both constituents affected the feeding behavior of fry so severely that growth was completely stopped during the first twenty days of exposure. Some fish died after exposure to the toxicants; 38% of fry exposed to the highest concentration of toluene died during the first two days of exposure and all fry exposed to the highest concentration of naphthalene died on the first day of exposure.

The authors note that these and other aromatic compounds combined are probably responsible for inhibition of growth by crude oil. It is also noted that toxic concentrations are more likely in winter because ice and low temperatures limit evaporation and biodegradation of aromatic compounds. This study provides us with potential risks to coldwater fisheries exposed to concentrations of petroleum pollutants. The results can lead to poor fitness and production of fish, decreased growth, and an increased vulnerability to predation.

Nystrom, R.R. and G. Post. 1982. Chronic effects of ammonia-stripped oil shale retort water on fishes, birds, and mammals. Bulletin of Environmental Contaminants and Toxicology 28: 271-276.

This study was conducted in an attempt to find the effects of chronic low-level exposure of fish and wildlife to partially treated oil shale retort water. Rainbow trout (*Oncorhynchus mykiss*) and fathead minnows (*Pimephales promelas*) along with various aves and mammalian species were exposed to low levels of ammonia-stripped retort water through various routes and cytological and/or histological changes were monitored.

Fish eggs were obtained and cultured under constant flows and fed accordingly. Fish were then divided into 10 groups consisting of high dose exposures, low dose exposures and control groups. The exposure levels had to be lowered during the course of this experiment, after 85% mortality occurred in the high dose rainbow trout group #1. Results of this study indicated that at lowered levels of exposure, ammonia-stripping may be an important treatment step in reducing the potential harmful effects of retort water to fish and wildlife.

Ostrander, G.K., J.J. Anderson, J.P. Fisher, M. L. Landolt, R.M. Kocan. 1990. Decreased performance of rainbow trout *Oncorhynchus mykiss* emergence behaviors following embryonic exposure to benzo[a]pyrene. Fishery Bulletin 88:551-555.

This report studied the emergence behaviors following embryonic benzo[a]pyrene exposure in the emergence success and upstream swimming behavior of rainbow trout (*Oncorhynchus mykiss*). The authors note that this aromatic hydrocarbon finds its way into aquatic ecosystems from forest fires, industrial emissions, oil spills, automobile exhaust, and burning coal.

Embryos were exposed for 24 hours to 25µg/mL of benzo[a]pyrene 1 week prior to hatching. Exposures occurred during the later periods of development so that it could be determined the effects that exposure might have on emergence behaviors. Results indicated a decreased ability to swim upstream after emergence suggesting that exposure to low levels of toxicants may be detrimental to early life history behaviors that are necessary for survival.

It was noted that although the concentration of B[a]P used in this study is not typical of what occurs in nature, it may predict what could happen following some type of major accidental spill or discharge. It was also noted, given that a single 24 hr pulse of B[a]P elicited significant behavioral changes, future studies should be directed at understanding the potential effects of low-level chronic exposures which may more accurately mimic natural conditions.

Parker, B.L., J.D. Brammer, M.E. Whalon, and W.O. Berry. 1976. Chronic oil contamination and aquatic organisms with emphasis on diptera: status and bibliography. Water Resources Bulletin 12: 291-305.

This paper provides an overview of the problems that arise when petroleum is introduced to freshwater environments with an emphasis on diptera species. The authors discuss fouling of scenic waters, swimming areas, and fishing regions resulting in millions of dollars worth of damage as a result of oil contamination. The paper also discusses many cases and observations in which petroleum contaminants deleteriously affected aquatic resources.

This paper provides an extensive bibliography on the available research that is relevant to issues concerning chronic oil contamination in freshwater systems. This work was assembled to avoid gross duplication and to facilitate planning for future investigations on chronic oil spills on aquatic dipterans, a valuable food source for many stream fishes.

Pollino, C.A. and D.A. Holdway. 2002. Toxicity testing of crude oil and related compounds using early life history stages of the crimson-spotted rainbowfish (*Melanotaenia fluviatilis*). Ecotoxicology and Environmental Safety 52:180-189.

This study focused on the toxicity of crude oil and related compounds on the sensitive early life stages of the crimson-spotted rainbowfish (*Melanotaenia fluviatilis*), a native of Australia. The objectives of this study were: (a) to measure the acute toxicity of embryonic rainbowfish to the water-accommodated fraction of crude oil (WAF); (b) to compare acute toxicities of WAF, dispersants, dispersed crude oil water allowable fractions (DCWAF), and naphthalene to larval rainbowfish; (c) to compare naphthalene 96-h LC-50 values of larvae collected from adult rainbowfish exposed to one of untreated water, WAF, DCWAF, and naphthalene during their embryonic period.

Results showed that although WAF was not acutely toxic to embryonic rainbowfish during the 96 h exposure period, developmental abnormalities that affect survival were observed prior too and after hatching. In this study, hatchability and the incidence of larval deformities were decreased at 0.5 mg/L total petroleum hydrocarbons (TPH) and above. Also in this study, the incidence of abnormalities in rainbowfish larvae continued to increase in developing rainbowfish after completion of the 96-h exposure, suggesting petroleum hydrocarbons may have accumulated in the yolk sac. Rainbowfish in this study had the highest sensitivity to naphthalene and larval fish were more susceptible than embryos to crude oils.

This study cites many other useful studies investigating the toxicity of crude oils to other species, most of which shared common results such as cranial, jaw, and notochord anomalies. A spillage of crude oil or petrochemicals can occur during extraction, refining, transport, or use. Further impacts during energy development should be heavily monitored, evaluated, and taken into account when point- or non-point sources have potential to enter aquatic systems.

Ramirez Jr., P. 2005. Assessment of contaminants associated with coalbed methane produced water and its suitability for wetland creation or enhancement projects. U.S. Fish and Wildlife Service Contaminant Report R6/721C/05, Cheyenne, Wyoming.

This report addresses issues relating to coalbed methane (CBM) product water and its management in the Powder River Basin, Wyoming. The study was conducted from 2000-2002 to identify contaminant risks to aquatic organisms and aquatic migratory birds from the creation/enhancement of wetlands with CBM produced water. Water quality data from a number of existing CBM discharges in the Powder River Basin was collected as well as samples of water, sediment, aquatic vegetation, aquatic invertebrates, fish and amphibians. All samples were submitted to laboratories for various analyses.

Results of the study showed that waterborne copper, iron, lead, and manganese exceeded chronic criteria in several CBM water receiving impoundments. Arsenic, cadmium, nickel, and zinc in sediments from a terminal sink exceeded threshold effects concentrations for sediment dwelling organisms. Cadmium and chromium found in aquatic invertebrates and pondweed, respectively from terminal sink sites were

elevated. Selenium levels in waters associated with CBM discharge water were above the threshold for bioaccumulation in sensitive fish species. Chromium concentrations in fathead minnows (*Pimephales promelas*) associated with CBM product water were extremely elevated. Sodium was also found in highly elevated levels in CBM produced waters.

The author explains many implications that can arise from different trace elements involved with CBM produced water including adverse impacts to riparian vegetation, fish, wildlife, and overall habitat quality. It was noted that in order to prevent adverse impacts to fish, wildlife and their habitats, CBM operators, land managers, and land owners should evaluate the disposal options for CBM produced water on a site by site basis. There are a number of well advised management recommendations included in this report.

Sprague, J.B., and W.J. Logan. 1979. Separate and joint toxicity to rainbow trout of substances used in drilling fluids for oil exploration. Environmental Pollution 19: 269-281.

This work was done in response to the questions of whether or not disposal of drilling fluid into water was a serious hazard to aquatic organisms and whether different proportions of the more toxic components would change the overall toxicity of the mixture in a predictable fashion. The purpose of this study was to determine: 1) toxicity to a coldwater fish of whole drilling fluids, of their common components, and of rig-washing surfactants that would mix with used fluid; 2) predictability of toxic interactions of chemical components in standard drilling fluids; and 3) preliminary indication of any change in toxicity when components were allowed to age in water.

Different components and compositions of drilling fluid were used in 4 day static bioassay tests on rainbow trout (*Oncorhynchus mykiss*). It should be noted that in more recent studies, static bioassay tests have shown to give deceptively high results for lethal concentrations because the actual concentration of the test compound is likely to be lower than the dosed concentration in the test chambers because of evaporation, adsorption, and accumulation.

The authors reported that many of the organic materials used in small quantities in drilling fluids had reasonably low toxicity. Five of the six surfactants used in drilling fluids were reported as being fairly toxic. The authors note that it would be prudent, in situations where used fluids might reach natural waters, to substitute less toxic components of similar function.

Tahir, A. and C.J. Secombes. 1995. The effects of diesel oil-based drilling mud extracts on immune responses of rainbow trout. Archives of Environmental Contamination and Toxicology 29: 27-32.

This study was designed to investigate the potential suppressive effect of oil-pollution in the aquatic environment on fish immune responses. Rainbow trout (*Oncorhynchus mykiss*) were injected with increasing doses of an extract obtained from diesel based oil-drilling mud. Fish were monitored for six weeks then sacrificed to determine immune parameters. In a second experiment, fish were exposed to either the extract or saline and immune parameters were monitored 2, 4, 6, and 8 weeks post-injection.

It was concluded that immune responses for rainbow trout were affected by intraperitoneal exposure to an extract from diesel oil-based drilling mud, with both stimulatory and inhibitory effects being evident. The authors note that as fish inhabit aquatic environments, their immunological defense system may be susceptible to adverse changes in water quality conditions and that environmental pollutants have been suspected to contribute to outbreaks of infectious diseases in fish. It should be noted that if fish in controlled environments can show changes in immune system efficiency through simulated experiments, stream fish should be monitored and evaluated as any changes in water quality occur due to point- and non-point source pollutants entering aquatic ecosystems as a result of energy development.

USGS (U.S. Geological Survey). 2006. Toxicity of sodium bicarbonate to fish from coal-bed natural gas production in the Tongue and Powder River drainages, Montana and Wyoming. Fact Sheet 2006-3092

This study evaluates the sensitivity of aquatic life to sodium bicarbonate ($NaHCO_3$), a major constituent of coal-bed natural gas-produced water. The focus area for this project includes the Tongue and Powder River drainages within the Powder River Basin in southeastern Montana and northeastern Wyoming.

Acute and chronic toxicity experiments were designed to determine the median lethal concentration of sodium bicarbonate to three species of fish which are native to the Powder River drainage, 1) fathead minnow (*Pimephales promelas*), 2) white sucker (*Catostomus commersonii*), and 3) pallid sturgeon (*Scaphirhynchus albus*). Results of the chronic toxicity experiments indicated that survival in fathead minnows was significantly less than the controls in all sodium bicarbonate concentrations above 400mg/L. As concentration and exposure time increased, so did the occurrence and severity of microscopic lesions, as well as incidences of kidney damage.

This study shows that along with increasing amounts of sodium bicarbonate in water significant increases in mortality can be expected. The authors state that after 96 h, concentrations of sodium bicarbonate of 1100 to 1600 mg/L will cause 50% mortality in early life stages of these fish in the drainage area, furthermore, that significant mortalities of greater that 30% will occur if fish in the Tongue River are exposed to 400mg/L of sodium bicarbonate for 30 days.

Woodward, D.F., P.M. Mehrle, Jr., and W.L. Mauck. 1981. Accumulation of a Wyoming crude oil in cutthroat trout. Transactions of the American Fisheries Society 110:437-445.

This study was designed to investigate the chronic toxicity of a Wyoming crude oil to cutthroat trout (*Oncorhynchus clarki*) in order to provide data for establishing oil-effluent limitations for protecting fishery resources. At the time of the study, allowable discharges in Colorado, Montana, and Wyoming were an aesthetic-based limit of 10mg/L. The EPA recommended concentration was a significantly lower 24 µg/L.

Cutthroat trout were exposed for 90 days to four concentrations of a Wyoming crude oil in water ranging from 100 – 520 µg/L. In the highest concentration survival was reduced to 52%. All concentrations had an adverse effect on growth. Exposure to elevated concentrations of oil also resulted in gill lesions, caudal fin erosion and lesions of the lens and eyes.

It was determined that the existing 10mg/L oil-effluent limit was too high. Based on the results of the study, the authors supported the EPA's recommendation of a 400X lower limit of 24µg/L allowable concentration. It was noted that this limitation would more adequately protect salmonids in natural waters.

Woodward, D.F., R.G. Riley, and C.E. Smith. 1983. Accumulation, sublethal effects, and safe concentration of a refined oil as evaluated with cutthroat trout. Archives of Environmental Contamination and Toxicology 12: 455-464.

This study exposed cutthroat trout (*Oncorhynchus clarki*) for 90 days in a laboratory to a refined oil collected from the North Platte River at a seepage site below the American Oil Company refinery at Casper, Wyoming. The purpose of this research was to provide a better understanding of the effects of chronic exposure to oil on fish and to test an oil that was contaminating a fishery habitat so to determine maximum no-effect concentrations.

Fish were exposed to five concentrations of the refined oil in a controlled environment, while seven biological responses (survival, growth, gill pathology, liver pathology, caudal fin erosion, caudal fin pathology and swimming performance) were evaluated and correlated with increasing water concentration and tissue accumulation of petroleum hydrocarbons. Fish exposed to the lowest concentrations showed mean tissue concentrations of 1.2µg/L total napthalenes, but showed similar responses to control fish to all biological responses. As oil concentrations increased so did adverse reactions to all seven biological

responses. At a concentration of 183µg/L fish responded adversely to all seven biological measurements. It was recommended that a no-impact safe limit for this oil and cutthroat trout is between 24 and 39µg/L.

Studies such as this are essential to allow development of western oil resources while protecting freshwater ecosystems. The authors note that as more lands in the western U.S. are made available for energy development and increased oil production, there will be an increased burden on western waters to absorb discharges of crude and refined oil products. To adequately protect fisheries in the region, discharges should be strictly regulated so that no-effect concentrations are maintained.

Woodward, D.F., R.G. Riley, M.G. Henry, J.S. Meyer, and T.R. Garland. 1985. Leaching retorted oil shale: Assessing the toxicity to Colorado squawfish, fathead minnows, and two food chain organisms. Transactions of the American Fisheries Society 114: 887-894.

The purpose of this study was to determine acute and partially chronic effects of a spent shale leachate on two fish species and two food-chain organisms and to determine the correlation of any effects with concentrations of salts, metals, and organics. Tests were conducted on Colorado squawfish (*Ptychocheilus lucius*), fathead minnow (*Pimephales promelas*) as well as Daphnia (*Daphnia magna*) and a species of mayfly (*Hexagenia bilineata*) to determine the effects that result from leachates of spent shale and its constituents (salts, metals, and organics).

The results of this study suggest that with increasing concentrations of leachate entering the water a decreased survival of the study organisms can be expected. The authors note that discharge of retorted shale leachate into the Colorado River system should take into account the high concentration of inorganic ions in the leachate, the already high level of dissolved solids in the river system, and the dilution factor between quantity of leachate discharged and volume of receiving stream. Special emphasis should be placed on flow characteristics of backwater habitats to prevent an increased residence time of leachates.

Woodward, D.F., E.E. Little, L.M. Smith. 1987. Toxicity of five shale oils to fish and aquatic invertebrates. Archives of Environmental Contaminants and Toxicology. 16: 239-246.

The chemical composition and toxicity of three shale crude oils, a hydrotreated oil, and a refined shale oil were assessed to determine the potential hazards to native fish species and food chain organisms posed by accidental spills of such materials. The objective of this research was to initiate a data base that would aid in the development of shale resources by providing information needed in hazard assessment and protection of endangered fish and aquatic organisms in the impacted area.

Colorado squawfish (*Ptchocheilus lucius*), fathead minnow (*Pimephales promelas*), cutthroat trout (*Oncorhynchus clarki*), and colonies of aquatic invertebrates were exposed to water soluble fractions of the shale oils for 96 h to determine LC-50 concentrations. The behavior of surviving fish was also measured to determine sublethal influences of exposure. Separate cold- and warmwater tests were performed in laboratory flow-through tests under increasing concentrations of oil exposure. Results showed a decrease in total number of aquatic invertebrates and both total number and diversity of taxa, as exposure concentrations increased. Cutthroat trout were the most sensitive of the fish species to exposures followed by fathead minnow and Colorado pikeminnow. Sublethal effects were observed at levels far below those of acute toxicity and included such responses as predator success and swimming performance.

It is noted that the most concentrated areas of oil shale deposits are in the Green River Formation in Colorado, Utah, and Wyoming. As production increases, exposure of aquatic organisms to oils also increases. Streams draining the development areas are tributaries of the upper Colorado River system, and support an important sport fishery as well as habitat for many native species. It should be noted that in order to adequately protect the natural diversity and integrity of the river system impacts should be further evaluated, monitored, and minimized.

Woodward, D.F., W.G. Brumbaugh, A.J. DeLonay, E.E. Little, and C.E. Smith. 1994. Effects of rainbow trout fry of a metal-contaminated diet of benthic invertebrates from the Clark Fork River, Montana. Transactions of the American Fisheries Society 123:51-62.

The purpose of this study was to determine if the biology and metal concentrations of age-0 rainbow trout (*Oncorhynchus mykiss*) would be affected by exposure to water and a diet of aquatic invertebrates' representative of conditions in the Clark Fork River. This was a system in which recruitment seemed to be limiting trout populations, a problem which was attributed to poor water quality associated with elevated metal concentrations. Metals concentrations in aquatic insects in the Clark Fork were 2-14 times greater than concentrations in the same taxa from less-contaminated tributaries.

Rainbow trout were exposed immediately after hatching for 91 days to heavy metals in water at concentrations simulating those in the Clark Fork River, Montana. Fry were also fed benthic invertebrates from the Clark Fork River that contained elevated concentrations of metals. The metals most frequently elevated in water, sediment, and biota, of this basin include: As, Cd, Cu, Pb, and Zn. These fish were compared with fry fed diets from reference systems with no history of metal impacts.

Results of this study indicated that survival of rainbow trout was significantly reduced by exposure to the Clark Fork invertebrate (CFI) diet. By day 42, survival of fish fed the CFI diets in all water treatments was significantly lower than those fed the reference diet. Exposure to metals through the CFI diet also significantly reduced growth, regardless of water exposure. Livers of fish fed the CFI diet also exhibited degenerative changes and generally lacked glycogen vacuolation. The authors concluded that Clark Fork invertebrates were the major source of the metals that accumulated in rainbow trout fry used in this study. It was also determined that the accumulated metals in those fry caused decreased growth and survival, thus leading to low recruitment and poor productivity.

Habitat and Species Assessment and Management

-- including information on sportfish populations, management strategies, and habitat evaluation

Bramblett, R.G., T.R. Johnson, A.V. Zale, D.G. Heggem. 2005. Development and evaluation of a fish assemblage index of biotic integrity for northwestern Great Plains streams. Transactions of the American Fisheries Society 134:624-640.

This study focused on creating an index of biotic integrity (IBI) for streams of the northwestern Great Plains. The IBI approach to stream assessment involves determining which biological attributes (metrics), of the targeted fish assemblage are most responsive to human influence and least influenced by temporal variation or natural gradients. This standardized approach to stream ecosystem assessment can be a valuable tool in determining how land use and other anthropogenic disturbances affect streams within a given region.

The objective of this study was to test the framework of IBI in a semiarid region characterized by high physiochemical variability, low species richness, and often subtle anthropogenic influences. The authors developed and evaluated a multimetric IBI based on fish assemblages for use in streams of the northwestern Great Plains region. The area studied was drained by the Missouri River and its tributaries, including the Yellowstone and Little Missouri Rivers. Land use in this area consists primarily of grazing, agriculture, coal, oil, and coalbed natural gas development.

Results of this study indicate that the IBI was demonstrably responsive to gradients of human influence, was not correlated with natural features, was temporally stable, and retained the ecological foundation of the original IBI. The authors noted that these factors are important because successful biological assessment requires accurate measurement of biological attributes that are correlated with severity of anthropogenic disturbances. A standardized approach to stream ecosystem evaluation and monitoring, such as this, will be vital to maintaining biological integrity of streams within development areas.

Clark, M.L., K.A. Miller, and M.L. Brooks. 2001. USGS. Monitoring of Powder River Basin stream-water quantity and quality. USGS Water Resource Investigations Report 01-4279 8p.

This report was provided in response to concerns by ranchers, water managers, and others concerned about the quality of coalbed methane discharge water and the effect that it may have on stream-water quality in the Powder River Basin. The authors note that understanding the effects of coalbed methane is complicated by stream hydrology, chemistry, land-use and climate. This report summarizes monitoring techniques used to determine overall effects of produced water.

The USGS has been monitoring stream flow and water quality in the Powder River Basin since about 1900. The results of this consistent monitoring approach provide a good baseline to determine land-use changes that affect water quality within the basin. This report summarizes available data and relations that may be useful in assessing water quality changes. It also identifies sites for monitoring streamflow and water quality in pre- and post- coalbed methane discharge areas which will provide for a real-time analysis as discharge occurs. It should be noted that consistent monitoring such as this is vital in determining the overall effects that development brings to water quality.

Colyer, W.T., J.L. Kershner, and R.H. Hilderbrand. 2005. Movements of fluvial Bonneville cutthroat trout in the Thomas Fork of the Bear River, Idaho – Wyoming. Transactions of the American Fisheries Society 25:954-963.

This research was intended to extend the knowledge of movements and home range requirements of fluvial cutthroat trout. The objectives of this study were to 1) determine the extent of seasonal home ranges and mobility of Bonneville cutthroat trout (*Oncorhynchus clarki utah*) (BCT) in the Thomas Fork and main-stem Bear River and 2) evaluate the role of a water diversion structure functioning as a seasonal migration barrier to fish movement.

Fish in the Thomas Fork of the Bear River, Idaho, were captured, radio tagged, and tracked for two years to determine mobility, seasonal home ranges, and to obtain a better understanding of spatial requirements. Results of the study showed that fluvial BCT were extremely mobile throughout the year and that they have

extensive winter ranges as well as a large mobile population component. The authors also found evidence of life history interruptions due to the observed impacts of a diversion barrier on the study population. Observations in this study provided the first documentation of a fluvial connection between tributary resident BCT populations in the upper Thomas and Smith's forks and main-stem fluvial populations in the Bear River.

The authors state that the extensive home ranges, large-scale seasonal migrations, and mobile component in the study suggest that effective conservation of fluvial BCT will require management at much larger spatial scales than are typically considered for interior cutthroat trout. The authors suggest that conservation approaches that focus only on headwater systems are incomplete and that maintenance of migration corridors and stream connectivity and conservation of seasonally used habitats will be required to maintain populations of fluvial BCT in this system.

Confluence Consulting, Inc. 2003. Biological, physical, and chemical integrity of select streams in the Tongue River basin. Report prepared for the Bureau of Land Management, Miles City, Montana. 73 pp.

The purpose of this document was to provide guidance regarding the potential impacts of high concentrations of salts on aquatic life and fisheries in regions where coalbed methane production may alter aquatic ecosystems physically, biologically, and/or chemically. The authors reviewed scientific literature addressing the toxicity of salts as well as the current biological, chemical, and physical conditions in streams within the Tongue River basin.

The authors provide background information and certain characteristics of streams within the Tongue River basin that may potentially be impacted by coalbed methane development. It was recommended that these streams that might be impacted should be managed based on an understanding of the potential biological integrity of the area streams. Management should prevent direct or indirect disposal into streams harboring sensitive species assemblages. It was noted that due to the uncertainty of the effects of coalbed methane development on streams within the region an adaptive management approach should be warranted. This study also serves as a good source of compiled baseline data for streams in the Tongue River basin.

Goettl Jr., J.P., and J.W. Edde. 1978. Environmental effects of oil shale mining and processing: Part 1 – fishes of Piceance Creek, Colorado, prior to oil shale processing. Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Duluth, Minnesota, EPA-600/3-78-096.

This study was conducted in order to establish preoperational conditions of fish assemblages and populations prior to extensive oil shale processing in the region of Piceance Creek, Colorado. The major objectives of this study were to determine what species of fishes had currently inhabited Piceance Creek and to find out where they occur. In addition an attempt was made to summarize the previous work on the distribution of fishes in the Piceance Creek basin to determine previous land-use effects on the creek. Sampling stations were chosen so that they overlapped the stations sampled by previous investigators.

This report contains an extensive survey of fish assemblages and populations throughout Piceance Creek and its tributaries as well as an overview of the streams physical and chemical composition. The authors discuss potential impacts of oil shale mining such as dewatering of headwater spring supplies and changes in salinity due to leaching from oil shale spoils. Recommendations for development included in this report were; 1) to avoid detrimental physical and chemical changes in Piceance Creek, 2) to conduct a similar field study after processing has reached a more advanced stage so that future changes may be studied, and 3) laboratory and field experiments on the toxic effects to fishes of saline waters of different ionic composition. This report provides good baseline data for an area prior to development. Studies such as this should be conducted anytime there is potential for development so that effects of development are better known and impacts can be minimized.

Kershner, J.L., C.M. Bischoff, and D.L. Horan. 1997. Population, habitat, and genetic characteristics of Colorado River cutthroat trout in wilderness and nonwilderness stream sections in the Uinta Mountains of Utah and Wyoming. North American Journal of Fisheries Management 17:1134-1143.

This study compared stream populations, habitat, and genetic features of Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) (CRCT) in wilderness and nonwilderness areas of the Uinta Mountains of Utah and Wyoming. The objectives were to compare CRCT populations, habitat characteristics, and hybridization with rainbow trout in wilderness and nonwilderness streams, and to examine the role of wilderness lands in the protection of native cutthroat trout.

The authors surveyed, categorized, and sampled a total of 88 stream reaches within the study area. Results showed significant differences between wilderness and nonwilderness reaches. Adult CRCT densities were higher in wilderness reaches, while juvenile densities were higher in nonwilderness reaches. Both adult and juvenile lengths were significantly greater in wilderness reaches. Wilderness areas also showed much higher percentages of habitat complexity. Overall, wilderness areas contained higher densities and better conditioned adult CRCT.

The authors conclude that wilderness streams may present some of the best opportunities for managing populations of CRCT because they represent important anchoring points for the recovery of populations. It was noted that in many cases, wilderness areas provide important refuges for native species while the recovery of severely disturbed habitats take place. This should be taken into serious consideration as development may occur within certain watersheds.

Stagliano, D.M. 2006. Aquatic surveys and assessment within the Middle Powder River watershed. Report prepared for the Bureau of Land Management, Miles City, Montana 37pp.

The purpose of this report was to: 1) set up integrator sites; 2) assess aquatic community baseline data; 3) ID and interpret key watershed indicators (against reference condition standards) to determine aquatic condition status and trends before the development of coalbed methane wells in the immediate Middle Powder River watershed.

This report identifies future monitoring sites and recommends protocols for future monitoring efforts. Throughout the report data is compiled on habitat and water quality as well as fish and macroinvertebrate communities throughout the Middle Powder River Basin. Species of special concern were also addressed and recommendations on future monitoring were made. This report represents an assessment that can be used in an ecological community context to help quantify overall watershed health and identify focal concerns in the region. Reports such as these should play a major role in monitoring and evaluation as development occurs within a watershed as they will enable informed management decisions concerning aquatic health at a watershed planning scale.

The Ruckelshaus Institute of Environment and Natural Resources. 2005. Water production from coalbed methane development in Wyoming: a summary of quantity, quality and management options. Final Report prepared for the Office of the Governor State of Wyoming, 77pp.

This report was compiled in response to a series of questions on options for dealing with water produced through coalbed methane development. The main purpose of this report was to provide answers to these questions along with enough additional information to place the answers into context. This paper includes a good overview of coalbed methane production in Wyoming and cites the fact that there is very little water quality information that exists concerning produced water.

Main topics of this paper include the extent and value of the coalbed methane resource, water quality, water quantity, water management, disposal, treatment and use, economic issues, regulatory and legal issues, alternative technical, regulatory and statutory strategies, and review for future steps. This report provides

an excellent opportunity to review some of the background information and potential problems and weaknesses in coalbed methane water production and management.

U.S. Fish and Wildlife Service. 2001. Status review for Bonneville cutthroat trout (*Oncorhynchus clarki utah*). USDOI, FWS Regions 1 & 6, Portland, Oregon and Denver, Colorado 153pp. [http://www.r6.fws.gov/species/fish/bct/bct_status_review.pdf]

This report was compiled and analyzed with the best scientific and commercial data available on Bonneville cutthroat trout (*Oncorhynchus clarki utah*) (BCT) to complete a full status review on the species. This report served as a basis on whether or not to list the BCT as a federally threatened or endangered species. Information gathered for the purpose of this report included; genetic variability and purity of various subpopulations of BCT, population status and trends, management policies and conservation plans affecting BCT, and threats to the species.

This report provides a good background on status and past activities that threatened the persistence of BCT, as well as past actions to protect the species. The report discusses the ecology and life-history of the species and provides a status summary for each geographical unit in which BCT occur. Also, discussed in this report are potential threats to the long-term persistence of BCT and conservation actions which may prevent or minimize threats to current populations.

Young, M.K., tech. ed. 1995. Conservation assessment for inland cutthroat trout. General Technical Report RM-256. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, 61pp.

This report focused on five subspecies of inland cutthroat trout found largely on public lands in the Rocky Mountain and Intermountain West. The primary goal of this assessment was to identify the state of science for each subspecies of cutthroat trout and the secondary goal was to help managers make informed choices about the consequences of land management for these subspecies. Cutthroat trout subspecies covered in this report included Westslope (*Oncorhynchus clarki lewisi*), Colorado River (*O.c. pleuriticus*), Rio Grande (*O.c. virginalis*), Bonneville (*O.c. utah*), and Yellowstone (*O.c. bouvieri*).

For each subspecies accounted for in this work, a detailed description of life history, habitat relations, biotic interactions, reasons for concern, causes for decline, current management and needs are all discussed. The author notes that all subspecies documented in this report share the loss of populations throughout their historic ranges due to many factors including habitat loss and degradation. It is noted that in order to further manage for viable populations of each subspecies, extensive stream surveys are needed along with reestablished probable metapopulations and the protection and expansion of populations within their historical ranges.

Young, M.K., R.N. Schmal, T.W. Kohley, and V.G. Leonard. 1996. Conservation status of Colorado River cutthroat trout. General Technical Report RM-GTR-282. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, 32pp. [http://www.fs.fed.us/rm/pubs_rm/rm_gtr282.pdf].

For the purpose of this report, information was obtained from state and federal biologists and from state databases to determine the overall distribution and status of populations of Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*). This report discusses historical distribution and current management, reintroduced populations, genetic purity, barriers, land management, population status, and immediate needs among others.

This paper reveals the conclusion that only a small portion of genetically pure Colorado River cutthroat trout populations remain throughout the historic range. It was noted that grazing, stream-dewatering, and roads were the most frequently identified problems for waters containing Colorado River cutthroat trout. It should be noted that population status and historic land use could serve as a strong basis for determining future population trends as they relate to development.