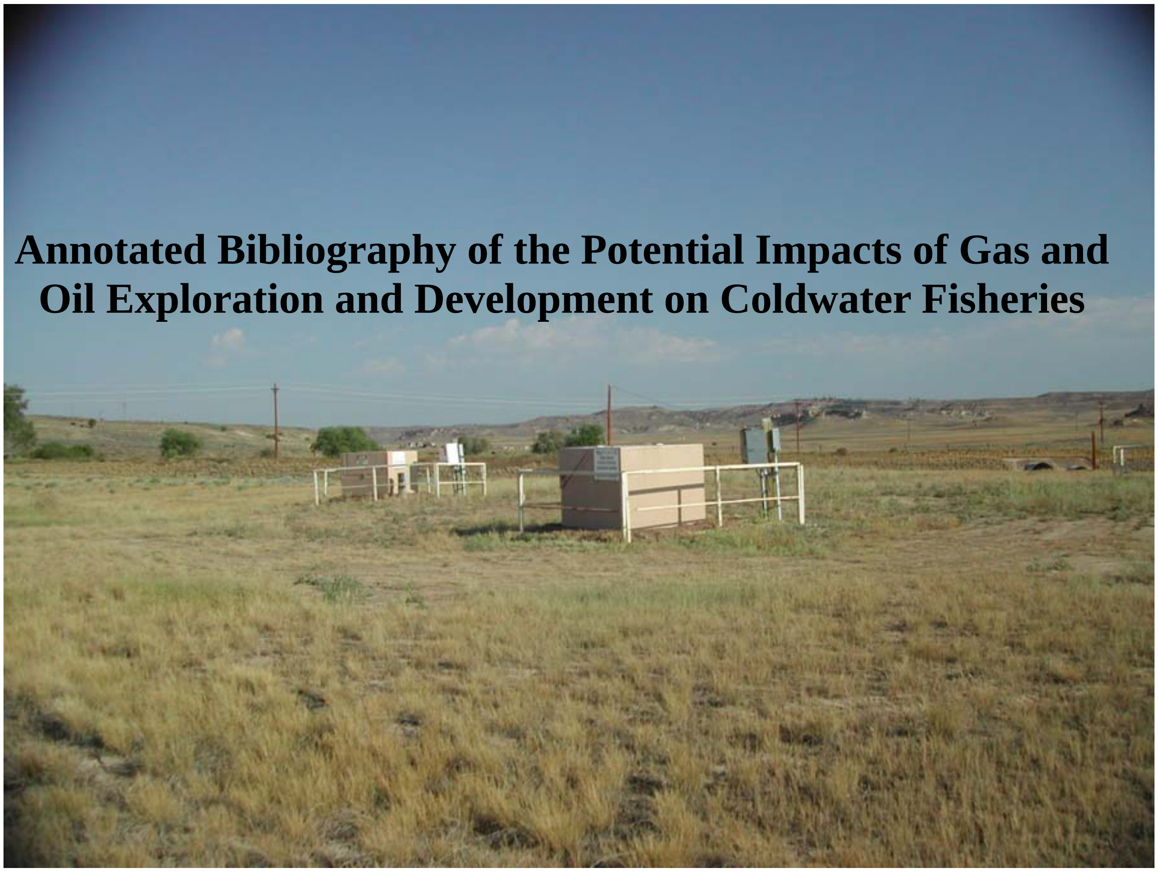
Annotated Bibliography of the Potential Impacts of Gas and Oil Exploration and Development on Coldwater Fisheries



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1.0 Introduction

Growing energy demands combined with desires for self-sufficiency in oil and gas production have increased pressures to develop domestic sources of energy. Oil and gas reserves in the Intermountain West are among those being considered for development. Increased exploration and development in this region has the potential to have negative effects on ecological conditions of terrestrial and aquatic ecosystems. Coldwater fisheries with significant recreational, economic, and biological importance may be among the natural resources affected by oil and gas development in this region.

An important tool for resource managers faced with avoiding, decreasing, or mitigating threats to natural resources – including coldwater fisheries and associated aquatic ecosystems – is an understanding of the potential impacts of oil and gas exploration and development on these resources. The objective of this document is to provide managers with a scientific basis for predicting these effects in order to promote sustainable oil and gas development practices with regard to coldwater fisheries. The first component of this document is an overview of the types and geographic scope of gas and oil development in the Intermountain West. The second component is an annotated bibliography of literature addressing impacts on groundwater, surface water quantity and quality, and fish and aquatic life. The third component is a summary of findings that details gaps in the literature that limit resource managers' ability to predict or mitigate potential injury to aquatic resources from oil and gas development. Finally, this document includes links to websites that provide information on this topic.

Several issues lie beyond the scope of this document. For example, a sizeable amount of research exists that examines the effects of offshore development on marine species. Inclusion of these studies in this effort was appropriate only if results applied directly to freshwater species. Another issue that was outside the scope of this document was the effects of certain elements of infrastructure such as roads or other surface disturbances on coldwater fisheries. A significant body of literature already exists addressing these effects (see Meehan 1991 for an overview).

2.0 Overview of Oil and Gas Exploration and Development in the Rocky Mountain Intermountain West

This section presents a synopsis of the major types of oil and gas activities in the Intermountain West, the locations of the major basins, the stages of exploration and production, and the associated surface and subsurface impacts. Oil and gas resources in the Rocky Mountain and Intermountain West include two broad classes, conventional and non-conventional. Conventional energy development refers to the more traditional extractions of petroleum (oil) and natural gas from underground reservoirs. The nonconventional energy resources include oil and gas shale, low permeability (tight) sandstone gas, and coalbed methane (Kuuskraa 1999). The nonconventional industry includes resources considered in the past to be inaccessible, or not economically viable for commercial production due to technical and environmental impediments.

The increased incentive to expand our national energy supply has resulted in reconsideration of nonconventional energy sources. Nonconventional energy resources tend to have substantially greater environmental implications than conventional resources due to the increased complexity of producing these resources. Yet, as they are relatively recent developments, comparatively little information exists to evaluate the specific environmental effects related to exploration and development of nonconventional sources. As a result, there is a significant amount of uncertainty regarding the environmental consequences of this development.

Despite substantial reserves, production of oil and gas from the Intermountain West is more difficult than in less mountainous and more developed regions of the United States. Barriers to economically viable production in the Intermountain West are a result of both the rugged topography and relatively undeveloped and remote nature of the region. In addition, numerous hydrogeological characteristics can undermine viable production. These include shallow formations, limited fracturing, low quality and underpressured gas, and saturation of deposits with groundwater (Kuuskraa et al. 1999). Additionally, many of these areas are geographically remote and lack the necessary infrastructure to support large-scale commercial energy industry. As a result, current technological and economic resources are devoted to reducing these barriers to production in order to increase recoverability from these regions and meet rising energy demands (EIA 2000).

2.1 *Geographic Scope*

There are two major oil and gas bearing regions in the Intermountain West, the Rocky Mountain region and the Greater Green River Basin. Together, these two regions encompass Montana, Wyoming, North and South Dakota, Arizona, Colorado, New Mexico and Utah (RAND 2002). All of these states contain major geological basins with active and potential production for conventional and nonconventional oil and gas production. However, for each basin, there is a distinction between the actual underground resource volume and recoverable reserves – the discrepancy between the two determines where development is concentrated.

The major oil and gas basins in the Intermountain West include the Piceance Basin (Colorado and Utah), the Greater Green River Basin (southern Wyoming), The Powder River Basin (Wyoming and Montana), the San Juan Basin (Colorado and New Mexico), the Wind River Basin (Wyoming), and the Overthrust Belt of the Rocky Mountains in Montana (RAND 2002, USGS 1995). Several of these basins have long been in production for conventional oil and gas and are undergoing expansion of the industry as nonconventional extraction spreads into the region. For example, in the San Juan Basin, both natural gas and coalbed methane are being heavily developed, with over 18,000 wells currently operating in the basin. Other basins are experiencing an exponential growth in activity associated with relatively newer nonconventional industries, such as coalbed methane in the Powder River Basin. In addition, some of the regions are the primary focus of future energy strategies due to predictions for major growth in development associated with incentives to expand domestic energy supply. This is true for the oil shale industry in the Green River Basin, which has the largest deposits of oil shale in the world (Smith 1980). In the Rocky Mountain Front of Montana there is currently no commercial production, despite large reservoirs. Recent proposals have heavily targeted this region for both conventional and nonconventional energy production (EIA 2002).

2.2 *The Stages of Oil and Gas Production*

Although each type of oil and gas described here has production characteristics unique to its specific industry, there are aspects of oil and gas development that are common across these industries. Notably, there are five primary stages in oil and gas production that occur in sequential order: geologic analysis (to locate reserves), exploration (seismic, test hole drilling, etc), construction (installment of infrastructure), production, and reclamation (US EPA 2000). Installation of infrastructure and the accumulation of impacts to the landscape accompany all stages, with the exception of reclamation. The infrastructure is similar across industries and can include access roads, well sites, utility lines, transport lines, compressor stations, separation facilities for removal of impurities, railway connectors, and sump or water holding ponds. All of these elements of infrastructure cause direct disturbance to the landscape, resulting in destruction of soil and vegetation, increased runoff, and industry-associated solid waste (UNEP 1997). In addition to the incremental growth of infrastructure, there is the increased human activity inherent to the industry, including prolonged human presence and frequent traffic to the site for maintenance and upkeep.

2.3 *Types of Oil and Gas in the Intermountain West and Associated Production Impacts*

There are four major types of oil and gas development in the Intermountain West. The potential environmental impacts of these industries include the general effects related to the similarities in exploration and development among these resources. In addition, the unique nature of these energy resources results in the potential for environmental impacts specific to each industry.

Crude Oil and Natural Gas

Because production processes are very similar for crude oil and natural gas and as they often occur in the same reservoir, joint consideration of these energy sources is logical. Until relatively recently, drilling production focused solely on oil production and the additional natural gas was often burned off or flared as waste. Currently, both natural gas and oil production are priorities in energy production.

Both oil and natural gas are products of sequential burying and heating episodes over geologic time that resulted in the conversion of organic material to oil-saturated shale and natural gas (US EPA 1992). Eventually, the oil and gas were expelled from the sedimentary rock in which they were trapped and migrated into underground reservoir rocks. Both oil and gas are produced by drilling a hole into the reservoir rock, which releases the pressure allowing natural migration to the surface. Typically, in drilling for conventional oil and gas, underground pressure is sufficient to ensure high flow rates to the surface. This is not true for the nonconventional industries.

Prior to reaching the production stage, an initial step is to drill a well in order to access the underground reservoir. This generally takes from 1-3 months and involves the introduction of drilling fluid requiring disposal. The fluid aids in proper function of the well bit and bore hole and contains chemical additives to achieve this purpose. The drilling fluid, referred to as "mud" in its final form, is pumped in and then back out of the well bore (RAND 2002). The drilling mud contains the original additives, in addition to underground chemical contaminants encountered in drilling. These can include high concentrations of heavy metals and hydrogen sulfide.

According to the US Environmental Protection Agency (1987), each vertical foot drilled produces between 0.2 and 2.0 barrels of waste mud. The discharge of water-based mud to surrounding areas is subject to environmental regulation. Oil-based mud is not permitted for discharge and must be transported or disposed of on-site (US EPA 1987). At the pump site and the disposal site, there are additional environmental concerns regarding leaching of hazardous waste into surface and subsurface water and the resulting affects to aquatic vegetation and aquatic communities.

Oil Shale

Oil shale refers to a type of sedimentary rock containing high concentrations of organic matter that is convertible to oil or gas by processing. Extraction involves lowering groundwater to below the level of the oil shale, allowing mining from underground or pits. Processing, which involves heating the shale to 300 to 400 °C, releases the oil from the shale. Processing of oil shale occurs either on-site in the mine or at a refinery following transport of the rock. The Greater Green River Basin is the number one targeted area for oil shale production.

The oil shale industry was previously considered uneconomical due to the high environmental costs of the industry. The environmental impacts of oil shale primarily result from production of large volumes of highly saline wastewater and spent shale (waste rock). In addition, processing the shale uses considerable volumes of water, requiring up to three gallons of water to produce one gallon of oil (Smith 1980). The water is typically highly saline with elevated levels of several major ions and heavy metals (Brendow 2002). In addition to disposal of produced wastewater, leaching of salts, heavy metals, and organic compounds into surface waters from spent shale is a key environmental concern for this industry.

Low Permeability (Tight) Sandstone

Gas from tight sands makes up a relatively small portion of the national energy supply. However, there is a growing interest in the viability of this industry (OGJ 2003), similar to trends for other nonconventional sources such as oil shale and coalbed methane. Tight gas differs from conventional gas reserves in that the gas lies trapped in reservoirs with abnormally low pressure and low permeability. Extraction of tight gas is more complex than conventional resources because of the lower pressure at which the gas exists

(Johnson 1987). This results in an associated higher cost of drilling for this industry. Another impediment with tight gas production is the degree of water saturation in the reservoir. Despite these obstacles, intensive development of the tight gas is likely in the Piceance Basin (Colorado) and the Green River Basin (Wyoming).

Consistent with the trend in other nonconventional energy industries, well density associated with this resource has greatly increased to achieve commercially viable production of tight sandstone (Law and Spencer 1989). With an initial well density of 1 well/acre, pilot projects in the Piceance Basin of Colorado have increased well densities to 10 to 32 wells/acre. Increased well density results in a greater concentration of all related infrastructure and industry activity on the landscape. Consequently, there are much greater surface disturbance implications resulting from increased well density (MT DEIS 2002).

Coalbed Methane

Coalbed methane (coal gas) is a form of natural gas derived from coal deposits. Coalbed methane development involves extraction of methane from coal seams by reducing groundwater pressure that keeps the methane adsorbed to the coal. This requires pumping massive volumes of groundwater out of the deposit, which eventually allows the gas to migrate naturally to the surface (Rice 2000). In order to achieve economically viable production levels of coalbed methane, the well density has been greatly increased for this industry and ranges from 4 to 40 wells/acre. Coalbed methane is an emergent industry that is growing exponentially in the Powder River Basin (Wyoming) and San Juan Basin (Colorado and New Mexico). Both of these regions currently have between 15,000 and 20,000 producing wells.

The de-watering phase of coalbed methane is inherent to production and can last from six months to two years. A unit volume of coalbed methane generally produces 13.5 times the amount of water produced for a unit volume of gas (Lawrence 1993). The two methods of wastewater disposal currently employed are injection into underground reservoirs (San Juan Basin) and discharge into area watersheds (Powder River Basin). Both of these methods are controversial and have significant disturbance impacts. Disposal by injection has high economic costs in addition to a lack of information regarding the long-term implications of this disposal method.

The discharge of methane wastewater into area watersheds is a critical environmental impact for consideration, both because of the large quantities produced and the altered chemical composition of the wastewater. Produced water typically has elevated concentrations of major ions, resulting in a higher overall concentration of total dissolved solids (TDS) and increased sodium absorption ratio (SAR) (Rice et al. 2000). As a result of increased surface water flows, a variety of impacts can occur in the receiving stream including increased turbidity, sedimentation, erosion, altered hydrology and loss of in stream, benthic, and bank habitat. Because of altered chemical composition, studies have documented a change in the pH regime, temperature change, reductions in dissolved oxygen, and increased overall salinity (O’Neil et al. 1991, MT DEIS 2002). The impacts of increased flow volumes and altered composition occur simultaneously in the receiving watershed and incur cumulative disturbances to the aquatic community.

3.0 Annotated Bibliography

This chapter presents an annotated bibliography and critical review of articles addressing the effects of exploration and development of fossil fuels on fisheries, water quality, and groundwater resources. The annotations for each publication include a summary and inferences regarding implications for water quality and beneficial uses, especially coldwater fisheries. Reviewers included individuals with expertise in water quality, groundwater hydrology, stream ecology, and fisheries.

Barclay, C.M and R.C. Harrel. 1985. Effects of pollution effluents on two successive tributaries and Village Creek in southeastern Texas. Texas Journal of Science 37:175-188.

This study examined physicochemical conditions and benthic macroinvertebrate communities in streams receiving discharges from an oil refinery, a sawmill, and sewage treatment plant. All streams receiving direct discharges of effluent had poor water quality during low and normal flows. The stream receiving oil refinery effluent had “poor” water quality and low numbers of invertebrate taxa. Physicochemical conditions improved during higher flows although invertebrate communities did not rebound. The poor water quality did not extend below the receiving stream however; the authors cautioned that increased production and increased volume of effluent might have a deleterious effect downstream of the receiving waters.

Physicochemical parameters evaluated in this study were odd given the potential pollutants from an oil refinery. The investigators analyzed some common ions, nutrients, and suspended solids. Hydrocarbons and other toxics were not included in this evaluation. Salts were the identified constituents attributed to low water quality, although these were not at levels that negatively affect aquatic life. Therefore, while salts may comprise a portion of the effluent, organic compounds associated with crude oil were probably responsible for the impaired macroinvertebrate communities.

Blundon, D., M. Dale, S. Goudey, and J. Hoddinott. 1987. Effects of oil and oil spill chemicals on shoreline plants of northern freshwater ecosystems. Pp 403-409 *In*: Vandermeulen, J.H and S.E. Hrudey (eds.) Oil in Freshwater: Chemistry, Biology, Countermeasure Technology. Pergamon Press, Oxford, England.

This was an investigation of the response of several riparian species to oil dispersants and a reference toxicant (sodium lauryl sulfate). These treatments mimicked an oil spill and addition of dispersants to mitigate spills. Oil sprayed on foliage or poured onto soil caused the most damage to all species. Plants that survived the oil treatment were not harmed by the dispersants. Sedges and willows were the most tolerant of oils and dispersants. The least tolerant species included black spruce and sphagnum moss, species occurring in Arctic regions.

Toxicity of oil spills to riparian vegetative communities has significant implications for coldwater fisheries. Disruption of the numerous functional attributes of riparian vegetation has implications for stream morphology, water quality, and energy inputs to streams. These effects may last longer than the direct effects of toxic chemicals on fish and aquatic life.

Burk, C.J. 1977. A four year analysis of vegetation analysis following an oil spill in a freshwater marsh. Journal of Applied Ecology 14:515-522.

This study was an investigation of the response of marsh vegetation to an oil spill in Massachusetts. Vegetation types included riparian plants and aquatic macrophytes. While it was not possible to eliminate confounding variables such as floods, increased pollution from other sources, and species introductions (Canada geese), there was a decline in diversity and cover of marsh vegetation. This decline, combined with gradual recovery over the next two years, was largely attributable to the oil spill.

While not a coldwater system, the responses of riparian and aquatic vegetation to oil contamination have implications for coldwater fisheries. These communities have numerous functional attributes that maintain the physical, biological, and chemical integrity of streams. Disruption of these attributes results in alterations in water and habitat quality, which has a negative effect on fish and associated aquatic life.

Carls, M.G., L. Holland, M. Larsen, J.L. Lum, D.G. Mortensen, S.Y. Wang, and A.C. Wertheimer. 1996. Growth, feeding, and survival of pink salmon fry exposed to food contaminated with crude oil. American Fisheries Society Symposium 18:608-618.

This study examines marine residency stages of pink salmon fry. While marine fisheries are outside the scope of this annotated bibliography, this study has implications for salmonids of the genus *Oncorhynchus*. This merited its inclusion in this effort.

These investigators examined the response of pink salmon fry (*O. gorbuscha*) to ingested oils from contaminated foods. In the marine environment, ingestion was more common than coating in contaminating fry. Direct ingestion of oil-contaminated food can negatively affect the growth and survival of salmon fry. Feeding rate and survival of pink salmon fry given food contaminated with high oil concentrations (34.8 mg oil/g food) declined significantly. A combination of starvation and oil toxicity was responsible for mortality. Fry showed remarkable ability to recover when offered clean food. Lower concentrations of oil did not affect feeding rate, but growth was significantly depressed.

Confluence Consulting, Inc. 2003. Biological, physical, and chemical integrity of select streams in the Tongue River basin. Report prepared for Bureau of Land Management, Miles City, Montana. 106 pp.

The objectives of this study were to collect baseline data in streams with a potential for nearby coalbed methane development and to make comparisons above and below coalbed methane development on select streams. Factors influencing the rankings of integrity for evaluated streams included water quantity and flow characteristics and salt loading from natural sources. One site had markedly reduced biological and physical integrity compared to an internal reference above coalbed methane development, baseline data collected in the 1970s, and some ecoregion references. Without a source assessment to determine sources of salt loading in this stream, it was not possible to attribute conclusively the diminished water quality and biological integrity to coalbed methane development. Nevertheless, these results suggest that coalbed methane development may have significantly deleterious effects on fisheries, aquatic life, and water quality, even when there are not direct discharges permitted to surface waters.

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 is one of the few investigations into the effects of coalbed methane development on water quality and fisheries. Researchers sampled fish, macroinvertebrates, and periphyton (attached algae) at several sites along the Powder River, including sites above and below coalbed methane discharges in the basin. Other streams sampled in this effort included Clear Creek and its tributary, Piney Creek. Objectives of this study included characterizing baseline conditions prior to full development of coalbed methane operations, evaluating potential impacts of existing coalbed methane facilities, and devising recommendations to promote the sustainable development of coalbed methane.

Results from the Powder River sites suggest that coalbed methane development in the basin may be negatively affecting water quality. Several measures of dissolved solids were high compared to data for the Powder River stored in the US Geological Service’s database. Other identified concerns included the rarity of sturgeon chub, a species of special concern, and encroachment of tamarisk, a salt tolerant, introduced shrub that has the potential to outcompete the more desirable cottonwoods.

Although this study addressed warmwater systems, there are several implications for coldwater fisheries. Foremost, this study presents an assessment approach that provides a model for collection of baseline data to evaluate the impacts of energy development on streams in an adaptive management framework. This study entailed a three-assemblage approach (fish, benthic macroinvertebrates, and periphyton) as well as strategy to make inference on the effects of coalbed methane development in the absence of baseline data.

DeGraeve, 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.

Fathead minnows and rainbow trout were used in flow-through bioassays to determine the acute toxicity of benzene and naphthalene, constituents of crude oil and refined petroleum products. The flow-through methodology has advantages over static tests when testing volatile, relatively insoluble compounds. Flow-through systems maintain the desired concentrations of toxicants for the duration of the test.

Not surprisingly, naphthalene and benzene were toxic to both species. Moreover, these pollutants decreased egg hatchability and fry length of fathead minnows. Rainbow trout were more sensitive to both pollutants than the fathead minnow. The fathead minnow is widely recognized as being tolerant of pollution, yet is frequently used in bioassays to determine limits for concentrations of pollution. The results of this study emphasize the inadequacy of applying results obtained from bioassays using fathead minnows to more sensitive species, such as rainbow trout.

Dennington, V.N., J.J. George, and C.H.E. Wyborn. 1975. The effects of oils on growth of freshwater phytoplankton. Environmental Pollution 8:233-237.

This study investigated the effects of lubricating oil and diesel oil on two species of freshwater algae, *Euglena gracilis* and *Scenedesmus quadricauda.* Lack of information on the effects of oil spills on freshwater systems provided the impetus for this study. The authors sought to fill information gaps on effects of oil on primary producers. The *Euglena* grew in cultures containing up to 10 percent diesel oil and lubricating oils. The presence of lubricating oil reduced the growth of *Scenedesmus quadricauda,* while diesel oil halted growth of this species.

An important consideration in interpreting this paper is the high natural tolerance of these algae to organic pollutants. Out of 80 common algal taxa, *Euglena gracilis* and *Scenedesmus quadricauda* ranked 15th and 4th, respectively, in terms of tolerance to organic pollutants (Loren Bahls, Hannaea, personal communication). The response of these taxa to pollutants used in this study did not reflect these tolerance rankings; however, it is possible that they respond differently to various organic compounds

EPA. Exemption of oil and gas exploration and production wastes for federal hazardous waste regulations. Undated brochure. (http://www.epa.gov/epaoswer/other/oil/oil-gas.pdf)

This brochure describes exemptions of oil and gas exploration wastes from federal hazardous waste regulations. This exemption was part regulatory determination released by the EPA in 1988, which determined that the control of exploration and production wastes under the Resource Conservation and Recovery Act (RCRA) is not warranted. This exemption, referred to as the RCRA Subtitle C exemption, did not preclude these wastes from control under state regulations under the less stringent RCRA Subtitle D solid waste regulations, or under other federal regulations. In addition, this exemption does not imply these wastes could not present a hazard to human health and the environment if improperly managed.

In addition to the regulatory framework, this document provides statistics of volumes of drilling wastes generated in the US. The American Petroleum Institute (API) estimated that exploration and production operations generated 149 million barrels of drilling wastes, 17.9 billion barrels of produced water, and 20.6 million barrels of other associated wastes in 1995. Drilling waste production correlates with the level of drilling activity, while the volume of produce water increases as hydrocarbons from producing well are depleted.

The brochure provided no rationale for the RCRA Subtitle C exemptions and only one reference to benefits to oil and gas producers. The benefit of the RCRA exemption is that although the operator may still be liable for clean-up actions, the exemption allows the operator to choose a waste management and disposal option that is less stringent and possibly less costly than actions required under RCRA Subtitle C.

A concern associated with the exemption and resulting less stringent clean-up requirements relates to whether human health and the environment are adequately protected. Are the nearly 200 million barrels of waste generated each year being adequately disposed of or treated under the other state and federal regulatory mechanisms? We uncovered no resources to assess the ramifications of this exception on the environment near field operations.

Harrel, R.C. 1985. Effects of a crude oil spill on water quality and macrobenthos of a southeast Texas stream. Hydrobiologia 124:223-228.

This investigation followed the effects of a spill of nearly 7,000 gallons of oil into a stream in southeast Texas. An organized clean-up of the spill did not begin for six days following release of oil. By this time, many of the toxic aromatic compounds probably volatilized. Except for the presence of oil, it took six months for effects on water quality to manifest. Under physicochemical conditions of decreased flow and increased temperatures, carbon dioxide production increased while dissolved oxygen decreased. These conditions had a marked effect on macroinvertebrates. Worms increased substantially while chironomids (midge larvae), the only reported component of the insect fauna, decreased. These effects remained through the 26-month duration of the study.

Harrel, R.C. and T.C. Dorris. 1968. Stream order, morphometry, physico-chemical conditions, and community structure of benthic macroinvertebrates in an intermittent stream system. The American Midland Naturalist 80:220-251.

This study investigated the community structure of benthic macroinvertebrates across a range of stream orders, and physical and chemical gradients. Stream order refers to a numbering convention for streams where a headwater stream without tributaries is first order; two first order streams join to form a second order stream, and so on. Seepage of oil field brine upset the stream order-community relationship. An influx of low concentrations of oil field brines, sodium chloride, and sodium sulfate caused diversity per individual to increase and redundancy (lack of heterogeneity) to decrease, indicating improved stream conditions. Conversely, brines that were more concentrated caused diversity of macroinvertebrates per individual to decrease and redundancy to increase.

Oil wells occurred about 180 meters from the streams. Even with inflow of oil brines, dissolved solid concentrations in these streams were relatively low and similar to trout streams in the Intermountain West. Implications for coldwater fisheries from this study are that salts may be contributed to surface waters from oil wells. Low levels may have a positive effect. Higher concentrations, but still under 1000 mg/L may decrease diversity of aquatic macroinvertebrates.

Harrison, S.S. 1985. Contamination of aquifers by overpressuring the annulus of oil and gas wells. Groundwater 23(3).

This study evaluates the potential for shallow aquifer contamination associated with over-pressuring the unsealed portions of the well annulus in oil production wells. The author first discusses the effectiveness of surface casing, coupled with grouting the outer surface-casing void, in sealing off oil wells from shallow aquifer systems. The author notes that even if such surface casing is employed, it is still possible for the aquifer to become contaminated by the oil well if over-pressuring occurs in unsealed or unsealed portions of the oil well annulus. For instance, if the over-pressuring in an unsealed annulus leads to pressures exceeding the geologic strata pore pressure, then a net positive upward and/or outward flow gradient will evolve. This gradient may then lead to upward and/or outward transport of contaminants from zones of poorer water quality toward fresh-water aquifers. The author cites instances where subsurface entry of contaminants has affected fresh-water aquifers as a result of the conditions described above.

Two measures described by the author to minimize potential impacts include: 1) completely sealing the annulus above the production zone, or 2) operating the oil and gas well so that the boring annulus pressure never exceeds the normal (pore) pressure of the strata exposed to the annulus.

This paper is relevant to coldwater fisheries as it described conditions where adjacent fresh-water aquifer(s) may be impacted by over-pressuring of unsealed production well annuluses. In the event an impacted fresh-water aquifer is near a coldwater fishery, transport of contaminants via base flow from the aquifer to surface water may occur. Based on this potential risk, it may be appropriate to evaluate the current specifications or criteria that exist through regulations to ensure that oil wells do not cause cross-contamination of potentially vulnerable aquifers and hydraulically connected surface waters. In the event those criteria are insufficient, recommendations should follow to decrease risks.

Hedtke, S.F. and F.A. Puglisi. 1982. Short-term toxicity of five oils to four freshwater species. Archives of Environmental Contamination and Toxicity 11:425-430.

These authors conducted short-term lethality tests with five oils, both crude and refined, on freshwater species. The organisms tested included the American flagfish (*Jordanella floridae*), fathead minnow, larvae of the wood frog (*Rana sylvatica*), and larvae of the spotted salamander (*Ambystoma maculatum*). Oils were tested as floating layers, emulsions, and as the water-soluble fraction (WSF). Factors influencing the LC_{50} (lethal concentration for 50 percent of study organisms) included species tested, differences between batches of oil, the form of the oil when added to the test system, the type of test, duration of exposure, and the oil contact time.

Only the wood frog and fathead minnow were exposed to crude oil. The WSF was not toxic to wood frogs. Emulsions were toxic to both fathead minnow and wood frogs. Floating layers were relatively benign during the 24-hour test, but toxicity increased for the 96-hour test.

Hietkamp, M.A. and B.T Johnson. 1984. Impact of an oil field effluent on microbial activities in a Wyoming river. Canadian Journal of Microbiology 30:786-792.

This represents one of the few studies of the effects of oil development on a coldwater stream. Wastewater from the Union Oil Company’s Dallas field is discharged into the Little Popo Agie River, Wyoming. The purpose of this investigation was to observe the effect of chronic exposure to wastewater from an oil field on the survival, functions, and physiological diversity of autochthonous (produced instream) microbiota in the sediment of the Little Popo Agie River. These authors recognized that little data exist evaluating the effect of chronic petroleum hydrocarbon contamination, despite the fact that several western states permit direct discharge from crude oil production sites into streams and rivers.

The authors found that chronic exposure to oil field effluent stimulated microbial activity in stream sediments. Chronic exposure to hydrocarbons at levels known to be deleterious to fish and macroinvertebrates did not diminish the physiological diversity of microbiota. Furthermore, numbers of microorganisms, especially among those that degrade hydrocarbons, were elevated in sediments below oil wastewater discharges, indicating these biota may mitigate hydrocarbon pollution to some extent. However, sediment residues resulting in toxic exposures to macrobenthos result when deposition of hydrocarbons exceed natural, assimilative processes.

Mackay, D. 1987. Chemical and physical behavior of hydrocarbons in freshwater. Pp10-21. In: Vandermeulen, J.H and S.E. Hrudey (eds.) Oil in Freshwater: Chemistry, Biology, Countermeasure Technology. Pergamon Press, Oxford, England.

This paper presents a review of the behavior of hydrocarbons in freshwater systems. This author contends that much of the information acquired from investigations in marine environments can be translated to fresh water with a fair degree of reliability. There are five key processes that influence the fate of oil in water: photolysis, mousse formation (water –in-oil emulsification), dispersion, evaporation, and dissolution. The following is a description of these processes and implications for water quality and mitigation.

Photolysis.—Certain hydrocarbons can absorb photolytic energy and form active chemical species, which may be more soluble and more toxic than the parent hydrocarbon. The molecules may also have surfactant properties that may have a profound effect on mousse formation.

Mousse Formation.—Numerous complex factors control this water-in-oil emulsification process in marine environments. Investigations of this process in fresh water are rare, however it is likely that there are low emulsification rates related to this process:

1. formation of oil-in-water dispersions with the bulk of the oil being distributed throughout the water column with subsequent degradation, sorption, and sediment.
2. formation of stable masses of viscous water-in-oil emulsion on the surface which will drift eventually to shore, possibly as tar balls.

Dispersion.—Despite its importance, the mechanisms of dispersion are poorly understood. A particularly important and neglected aspect of dispersion is the behavior of oil slicks in rivers, in which it is likely that turbulence induces significant dispersion. Dispersion plays several key roles in determining the fate of oil. It is the principal determinant of a slick's duration and the principal method facilitating dissolution of hydrocarbons.

Oil Evaporation and Dissolution.—These processes are similar in that they result in the transfer of hydrocarbons from the oil phase into another receiving phase (air or water). Dissolution is especially important when considering oil toxicity on a hydrocarbon-specific basis. Dissolved hydrocarbons are readily transferred through biological membranes. The author presents numerous studies on investigations on evaporation and dissolution that are useful in predicting the fate of hydrocarbons from these processes.

Marty, G.D. J.W. Short. D.M. Dombach, N.H Willits, R.A. Hientz, S.D. Rice, J.J Stegeman, and D.E. Hinton. 1997. Ascites, premature emergence, increased gonadal cell apoptosis, and cytochrome P4501A induction in pink salmon larvae continuously exposed to oil contaminated gravel during development. Canadian Journal of Zoology 75:989-1007.

This study involved measuring the histopathology (tissue damage) and development of pink salmon larvae exposed to weathered Prudhoe Bay crude oil. Larvae exposed to various levels of oil contamination were sampled four weeks before emergence, at emergence, and 13 days after emergence. Larvae exposed to concentrations as low as 55.2 µg/g gravel of crude oil showed retarded development. Dissolution of oil in water mediated uptake of polynuclear aromatic hydrocarbons (PAHs). Oil-related changes included premature emergence, decreased metabolism of yolk, hepatocellular glycogen, and increased apoptosis (programmed cell death) of gonadal cells and midventral skin cells, and less food in the gastrointestinal tract. Effects on gonadal cells may be related to later reproductive impairment documented in field studies up to four years after the Exxon Valdez oil spill.

The results of this study beg the question of the appropriateness of the commonly applied 10 mg/L effluent limit for oil and grease. This is over 180 times the concentration resulting in retarded development of fry. The 10 mg/L effluent limit, based on concentrations resulting in a visible sheen, may have deleterious effects on incubating eggs or larval salmonids. These effects may also result in reduced fecundity of exposed fish.

McCart, P. and J. Densbeste. 1987. Colonization of experimentally oiled substrates by periphyton and benthic macroinvertebrates in two Arctic streams. Pp 387-402. In: Vandermeulen, J.H and S.E. Hrudey (eds.) Oil in Freshwater: Chemistry, Biology, Countermeasure Technology. Pergamon Press, Oxford, England.

This paper compares the recolonization by periphyton and benthic macroinvertebrates onto cleaned natural surfaces treated with Prudhoe Bay crude oil with a reference stream. Note there is an important distinction between recolonization of oiled substrates and not the potential effects of the oiling. Differences between the treated and control stream were not significant. This apparently limited response of periphyton and benthic invertebrate communities to oil contamination may be related to several factors. For example, the microhabitats where the baskets were placed (mid-channel of stony riffles) occurred where effects would be expected to be relatively minor. Furthermore, streams in remote areas have the ability to assimilate and reduce contamination due to the absence of chronic pollution. In addition, oligotrophic environments, such as the Arctic streams, may show a positive response to organic pollution. Finally, clean sediment from unoiled upstream sources could have covered the contaminated surfaces to mask any oiling effects on recolonization.

Millemann, R.E., S.J. Tumminia, J.L. Forte, and K.L. Daniels. 1984. Comparative toxicities of shale-derived crude oils and a petroleum-derived fuel oil to the freshwater snails *Helisoma trivolvis* and *Physa gyrina*. Environmental Pollution (Series A) 23-38.

The impetus for this study was to evaluate whether shale and coal-derived synthetic oils are less hazardous than petroleum to aquatic organisms. Shale oils are chemically different from petroleum. The objective of the study was to determine the acute and chronic effects of the water-soluble fractions (WSFs) of coal- and shale-derived oils and petroleum. Two species of snail were selected as study organisms due to typical factors: high reproductive output, ease of laboratory culture, and relatively short life history.

Shale oils and petroleum were toxic to both species of snail. The chemicals responsible for toxicity varied with the type of oil. Toxicity of petroleum WSFs is attributable to the presence of aromatic hydrocarbons. For the coal- and shale-derived oils, toxicity is due to high concentrations of phenols and bases in the water. In terms of relative toxicity, synthetic oils can be more hazardous than petroleum products to the aquatic environment.

Moles, A. 1980. Sensitivity of parasitized coho salmon fry to crude oil, toluene, and naphthalene. Transactions of the American Fisheries Society 109:293-297.

The objective of this study was to evaluate the sensitivity of coho fry with varying degrees of infestation by mussel glochidia, the larval, swimming stage of mussels. Parasites may increase the susceptibility of hosts to pollutants by damaging the host's tissue and withdrawal of nutrients necessary for normal host metabolism. The mussel-parasitized coho salmon had increased sensitivity to the toxicants compared to non-parasitized fish. These results suggest that oil contamination occurring when fish carry glochidia may have a greater effect at lower concentrations than would be predicted from standard toxicity tests from non-parasitized fish.

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 110:430436.

The objective this study was to evaluate the effect of sublethal concentrations of toluene and naphthalene on coho fry. Justification for this study was to evaluate risks to coldwater fisheries from crude oil spills from pipelines or during transport. Sublethal concentrations reduced growth and feeding behavior. These responses may reduce overall fitness of fry, increase the time required to rear in fresh water, and increase vulnerability to predation. In other words, sublethal concentrations of these constituents may reduce fitness of a given year class of salmonids subjected to an oil spill.

Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans. 1997. Stastical models to predict the toxicity of major ions to *Ceriodaphnia dubia*, *Daphnia magna*, and *Pimephales promelas*. Environmental Toxicology and Chemistry 16:2009-2019.

This study entailed development of statistical models to predict toxicity of major dissolved solids to several aquatic species, including two crustaceans and the fathead minnow. This study has implications for coldwater fisheries as conventional gas and oil development, oil shale, and coalbed methane development all have the potential to contribute dissolved solids to surface waters.

Toxicity varied among common ions. Potassium was the most toxic followed by magnesium, bicarbonate, chloride, and sulfate. Sodium, a constituent that limits the suitability of irrigation water, was not in and of itself toxic. Similarly, calcium was not toxic to the study organisms. Toxicity associated with these cations was due to the anion forming the respective salt.

The relative toxicity of different ions has implications for coldwater fisheries. Notably, much of the debate around coalbed methane development has focused on the high concentrations of sodium in waste water and its negative effect on irrigation uses. However, bicarbonate is the anion often associated with sodium in coalbed methane produced waters. Not only is the water rendered unsuitable for irrigation purposes, but also it may be toxic to aquatic life.

A consideration in applying this study to coldwater systems is the choice of study organisms. All are easily cultured species with a high reproductive output. In general, such organisms tend to be more tolerant of pollutants than species that do not adapt well to laboratory settings. Therefore, it is likely that concentrations of ions described here would be more toxic to sensitive salmonids or other coldwater fish and aquatic organisms.

Ostrander, G.K., J.J Anderson, J.P Fisher, M.L. Landolt, and 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.

Benzo[*a*]pyrene (B[*a*]P) is an aromatic hydrocarbon that finds its way into aquatic systems from forest fires, industrial emissions, oil spills, automobile exhaust, and coal burning. These authors found that sublethal doses of this compound resulted in a decreased ability to swim upstream after emergence from redds. These results indicate that low levels of toxicants may affect important early life history behaviors critical to survival. Through the concentration of B[*a*]P used in this study is not frequently encountered in nature, the value of this study lies in predicting what could happen following a major spill or discharge.

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 a monograph of the effects of petroleum contamination on freshwater aquatic life with an emphasis on mosquitoes. Introduction of oil to freshwater ponds resulted in lethal effects to invertebrates. Both the oil sheen at the surface, which physically blocked respiration among air breathing taxa, and soluble constituents were responsible for mortality. The use of petroleum products in mosquito control comprised a significant amount of the studies examined in this paper.

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 rainbow fish (*Melanotaenia fluviatilis*). Ecotoxicology and Environmental Safety 52:180-189.

This study investigated the toxicity of crude oil and dispersants used in preventing oil spills from reaching shorelines to crimson-spotted rainbow fish (*Melanotaenia fluviatilis*), a species native to southeast Australia. The authors acknowledged the risk associated with oil spills to the freshwater environment came during transportation and usage of crude oils. The oil/dispersant mixture was not acutely toxic to embryos, however, developmental abnormalities were observed prior to and after hatching. Larval rainbowfish mortality increased throughout the 96-h exposures to crude oil and dispersant mixtures. Dispersants along were not highly toxic to rainbowfish and were thus unlikely to cause additional mortality if used in an oil spill. Larvae were more susceptible than embryos to crude oils, probably because the chorion provided some protection.

This publication includes an excellent review of other studies investigating toxicity of crude oils to various species. Common effects of crude oil on embryos include cranial, jaw, and notochord anomalies. Descriptions of these resemble abnormalities associated with whirling disease. These similarities should be recognized in any effects analysis in streams impaired by whirling disease and oil contamination.

Ramirez, P., Jr. 2002. Oil field produced water discharges into wetlands in Wyoming. Contaminant Report No.: R6/718C/02. U.S. Fish & Wildlife Service, Region 6.

The focus of this study was on impacts from discharge of oil field produced water into surface waters, a permitted disposal option in Wyoming. Wyoming is one of the few states that allow discharge of oil field produced waters into surface water. Such a procedure is allowed in states west of the 98th meridian if the water is used for agriculture or wildlife propagation (40 CFR 435 subpart E).

In Wyoming, about 600 oil field produced discharges are permitted through Wyoming's National Pollution Discharge Elimination System (NPDES) permit program. A majority of Wyoming's NPDES permits are for oil field discharges. In some drainages, oil field produced waters constitute up to 89 percent of the stream discharges. Oil field waters typically include trace elements, hydrocarbons and radionuclides which tend to accumulate in the sediments and food chain.

The study collected data at 65 discharges to evaluate existing conditions from permitted oil field discharges. Water samples were collected at 12 randomly selected discharges. Most of the discharges (85 percent) went into Class 4 surface waters, which are deemed not to have the potential to support fish and include all intermittent streams. Note that this study also evaluated mortality to terrestrial wildlife, a topic outside the scope of this annotated bibliography.

Water discharged to surface waters had high levels of oil and grease. Produced waters at ten of the twelve evaluated discharges exceeded Wyoming State standards for oil and grease. Discharges generally exceeded the allowable by over 100 percent. One point of discharge in Park County, an area supporting coldwater fisheries, had a concentration of 54.2 mg/L of oil and grease. Note that other research addressing the effluent limit of 10 mg/L suggests it is not protective of fisheries or aquatic life (see Woodward et al. 1981)

This study has numerous implications for fisheries. First involves Wyoming's classification of intermittent waters as fishless. This is an erroneous assumption, particularly in grassland streams, which often support great diversity and abundance of fish despite intermittent flows. Although this has greater repercussions for warmwater fisheries, it is conceivable that intermittent streams supporting coldwater fisheries may also receive discharges of oil and grease contamination waters. Wyoming is in the process of revising their water use classifications, which may rectify this misclassification of intermittent streams as fishless.

Another issue involves hydrologic connectivity between presumably fishless waters and those supporting fish. Failing to address this ignores basic hydrological relationships and does not account for cumulative impacts in larger waters. Furthermore, the lack of monitoring beyond the point of discharge does not allow evaluation of the effects down the hydrologic gradient.

Finally, the extent to which the randomly selected discharges exceeded the effluent limits for oil and grease was particularly alarming. This suggests that existing safeguards are not sufficient to protect water quality and coldwater fisheries in watersheds with oil and gas production. Once again, the failure to monitor surface waters beyond the point of discharge presents an obstacle in protecting sensitive beneficial uses.

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 269-281.

This study investigated the toxicity of drilling fluids to rainbow trout. A concern in this study was evaluation of joint toxicity of diverse toxicants as opposed to considering toxicity of the various constituents separately. The objectives of the study were to determine: 1) toxicity to a cool-water fish of whole drilling fluids, their common components, and of rig-washing surfactants that would mix the 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.

Individual substances varied in toxicity to rainbow trout. Many of the organic materials, used as viscosifiers, had reasonably low toxicity. Paraformaldehyde, used as a bacteriocide, capryl alcohol, a defoamer, and most of the surfactants had relatively high toxicity. The authors recommend substituting less toxic components for these functions where fluids might reach natural waters.

Trett, M.W. 1989. Introduction. In: Green, J. and M.W. Trett (editors). The Fate and Effects of Oil in Freshwater. Elsevier Science Publishers, LTD. Essex, England.

This chapter presents a significant amount of information relevant to evaluating the effects of gas and oil production on coldwater fisheries. This annotation will focus on the effects of crude oil, while the chapter as a whole evaluates refined petroleum products as well. Crude oil is likely to enter fresh waters during either extraction or transport to refineries. An important consideration is the variability in chemical composition among crude oil deposits. Two reference sources provide the basis for much of the inference on potential environmental impacts of crude oil, south Louisiana and Kuwait. The applicability of these references to crude oil in the Intermountain West or other areas supporting coldwater fisheries is unknown.

Crude oils are chemically complex and the nomenclature used to describe the constituents varies between organic chemists and petroleum geologists and chemists (Table 1). The groups of organic constituents include alkanes, cyclalkanes, alkenes, and arenes. Within these groups are compounds such as benzene, toluene, pyrene, naphthalene. Water quality standards exist for allowable concentrations of these constituents due to toxicity or carcinogenic nature of these compounds. Other constituents in crude oil include metals such as vanadium and nickel, and other elements such as sulfur and nitrogen.

Table 1: Nomenclature and description of classes of constituents in crude oil.

Organic Chemists	**Petroleum Geologists and Chemists**	**Description**
Alkanes	paraffins	Open chain single carbon/carbon molecules
Cycloalkanes	Naphthenes or cycloparaffins	Alkane rings
Alkenes	olefins	Similar molecules to above but unsaturated
Arenes	Aromatics	Hydrocarbons with one or more benzene ring

Contamination of fresh water with crude oil is possible through several routes. Of primary concern is accidental leakage or spill into groundwater. According to Couillard (1986), widespread contamination of groundwater may occur from a large spill. In addition, groundwater contamination may occur due to over-pressurizing of gas and oil wells (Harrison 1985). In contrast, spillage of large quantities of crude oil into fresh water is an unusual occurrence. Despite the relative rarity, these authors cite several investigations into the effects of crude oil spills on freshwater environments.

The unique properties of crude oil from various sources provide a means to identify the specific source of pollution. The authors describe methods to determine the “fingerprint” of crude oil present in fresh waters. This ability is useful in prevention, remediation, and mitigation of waters contaminated with crude oil.

Tuvikene, A., S. Huuskonen, K. Koponen, O. Ritola, U. Mauer, and P. Lindstrom_Seppa. 1999. Oil shale processing as a source of aquatic pollution: Monitoring of the biologic effects in caged and feral freshwater fish. Environmental Health Perspectives 107:745-752.

The oil shale mining and processing industry in Estonia provides an unfortunate opportunity to study the effects of production unfettered by environmental regulations. Surface waters in the area receive pollution from oil shale mines and by leachate from the oil shale ash from thermal power plants among other sources. The main pollutants are sulfates, chlorides, oil products, heavy metals, and polycyclic hydrocarbons (PAHs).

The oil shale and mining processing area in northeast Estonia is heavily polluted with PAHs and other compounds. However, these authors reported few measurable, biologic effects in fish (rainbow trout, feral perch [*Perca fluviatilis*] and roach [*Rutilus rutilus*]). Measurable effects included bioaccumulation of PAHs in fish tissue at higher rates than expected; however, fish appeared to be able to withstand these toxic and carcinogenic compounds metabolically. The lack of histologically identifiable diseases in fish in this study contrasted to other studies of fish living in areas contaminated with aromatic hydrocarbons, chlorinated hydrocarbons, pesticides, and metals.

A considerable concern not addressed by these authors was the risks associated with consumption of fish that have accumulated PAHs and other carcinogenic/toxic compounds. The accumulation of PAHs above expected rates poses a potential risk to human health from eating contaminated fish.

Wallace, R.R. 1987. A review of oil and biological community responses in northern rivers. Pp 345-652 In: Vandermeulen, J.H and S.E. Hrudey (eds.) Oil in Freshwater: Chemistry, Biology, Countermeasure Technology. Pergamon Press, Oxford, England.

This paper addresses the community-level response of oil contamination in coldwater streams. Oil contamination of rivers includes catastrophic spills and chronic, low-level seep from natural sources or surface discharge through NPDES permits. Ecological effects from large spills result either from the toxic chemical effects or from the direct effects of physical coating, entanglement, and smothering. Effects from low-level contamination are harder to define and measure.

In a monograph of investigations of effects of chronic oil contamination of streams, this paper examines numerous trophic levels and assemblages (microbes to vertebrates). At the lowest level of organization, oil-degrading microbes are ubiquitous in stream receiving chronic, low levels of oil. Benthic macroinvertebrate taxa vary in their susceptibility to the oils. Moreover, factors such as oil type, season of exposure, and the nature of the receiving body influence the community response to oil contamination.

This paper also notes an apparent paradox between low levels of oil contamination and increased productivity from both periphyton and invertebrates. Similar responses are seen in oligotrophic, coldwater streams receiving organic inputs from sewage. Where nutrients are limiting, introduction of organic chemicals may stimulate production after the soluble, toxic fraction is reduced.

Wheaton, J. and J.M. Metesh. 2002. Potential ground-water drawdown and recovery from coalbed methane development in the Powder River Basin, Montana. Project completion report to the U.S. Bureau of Land Management. Open-File Report Montana Bureau of Mines and Geology 458.

The focus of this study by the Montana Bureau of Mines and Geology (MBMG) was to evaluate the potential impacts to ground water from coalbed methane (CBM) development in southeastern Montana using ground-water flow modeling. The specific modeling tool utilized was U.S.G.S. Modflow. The modeling effort allowed prediction of the relative declines in potentiometric head, especially in CBM aquifers, that may result from coalbed methane development.

The modeling effort used parameters consistent with geologic strata data that had been collected over the years in the Powder River Basin, especially data collected by the MBMG. The project area selected was close to active CBM operations near Decker, Montana. The simulation effort should be considered a “generic” model as a model calibration effort was not performed. The reason described by the MBMG for not conducting a calibration effort was that the site database is sparse outside the immediate vicinity of the coal-strip mining operations.

The strata targeted for the model simulations were the Anderson, Canyon and Wall coals, which are prime targets for CBM development. The cumulative water production after 20 years of pumping for the simulated regions was projected to be 400,000 acre-feet.

The maximum predicted drawdown was predicted to range from 220 feet to 550 feet within the domain of the active CBM development. Drawdowns exceeding 10 feet are projected to extend to about five to 10 miles outside the CBM development.

Conclusions drawn in the simulation effort were that flows from springs and the water available at wells supplying water for livestock, domestic and wildlife uses will be diminished or eliminated within the areas of drawdown. A long period of recovery is also projected, especially within the active/projected CBM development area.

Although not a focus of the modeling effort, a second issue described is the potential impact due to release of pumped CBM water, which tends to have high sodium adsorption ratio (SAR) and specific conductance (SC) values which can damage soils and may be toxic to plants.

The main conclusion relevant to fisheries is that CBM production may lead to reduced stream base flow during and following CBM production. In addition, stream water quality may be impacted by CBM production water, depending on how that production water is managed and controlled, particularly if that production water were to enter streams.

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

The Green River Formation in Colorado, Utah, and Wyoming has the highest concentration of oil shale deposits in the world. Synthetic crude oil produced from oil shale has been a viable substitute for petroleum since the 1940s. With nearly 90 percent of the world’s proven conventional reserves, this relatively small geographic area will face serious environmental challenges in the production and transport of this oil. Determining the toxicity of the water-soluble fraction (WSF) of shale oil to native fishes was the objective of this study. Species examined included warmwater species such as Colorado pikeminnow and fathead minnow, cutthroat trout (subspecies not reported) a coldwater species, and benthic macroinvertebrates.

Sensitivity to oil varied among study organisms. Cutthroat trout were the most sensitive of the fish species, followed by fathead chub and Colorado pikeminnow. Macroinvertebrate diversity and numbers decreased with increased exposure to oils. Sub-lethal effects included decreased swimming ability and predator success. While not directly lethal, decreased swimming and foraging abilities can deleteriously influence long-term survival.

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

The purposes of this study were to evaluate the chronic toxicity of a Wyoming crude oil to cutthroat trout in order to establish oil-effluent limitations to protect fisheries resources. The allowable oil discharge at this point for most states was 10 mg/L, a concentration based on aesthetics, not biological effects. Colorado, Montana, and Wyoming are among the states that prescribe this effluent limit.

Cutthroat trout (subspecies not reported) were exposed for 90 days to four concentrations of a Wyoming crude oil, ranging from 100 to 520 µg/L. The highest concentration reduced survival to 52 percent. All concentrations negatively affected growth. Exposure concentrations of 520 and 450 µg/L induced gill lesions and lesions of the lens and eye. Bioaccumulation of organic compounds in fish tissue correlated with concentration.

These authors concluded that existing allowable concentrations of 10-mg/L was too high. The EPA recommended considerably lower concentrations of oil and grease in effluent (24 µg/L). These authors supported this recommendation based on this research. Note that the allowable concentration is over 400 times the EPA recommended concentration.

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

This is another paper addressing the potential impacts of the oil shale industry slated for the Green River Formation in Colorado, Utah, and Wyoming. Development of shale oil involves disposal of large volumes of waste rock. Water percolating through these wastes could leach toxicants into surface waters. Salts are the primary constituents, although metals and organics also leach from retorted shales. Leachate had high concentrations of potassium, lithium, magnesium, molybdenum, sodium, and nitrate. These high concentrations of ions and anions resulted in concentrations of total dissolved solids (TDS) from 10,000 to 50,000 mg/L. For comparison, seawater has TDS around 30,000 mg/L. Increasing concentrations of leachate resulted in decreased survival of study organisms (fathead minnow, Colorado pikeminnow, and two species of mayfly).

4.0 Discussion and Recommendations

This annotated bibliography provides a basis for generalizing about the risks to coldwater fisheries related to the exploration and development of oil and gas resources. Just as importantly, this review of the available information provides a basis for identifying gaps in the available science that limit the ability to predict the potential environmental consequences and effectively mitigate those effects. Together, these provide a tool to resource managers and advocates to promote sustainable energy development that conserves coldwater fisheries.

4.1 *Water Quality*

Exploration and development of oil and gas has the potential to degrade water quality through several mechanisms and sources. Several types of pollutants are possible with these industries. Organic compounds, including toxics such as benzene and naphthalene, are possible with conventional oil and gas development and nonconventional energy sources such as oil shale and tight sand. Dissolved solids, including harmful or toxic salts comprised of sodium, bicarbonate, chloride, potassium, or sulfate are common. Other toxic constituents include metals and radionuclides. These constituents are present in either the gas or oil, or in wastewaters or waste rock.

Sources of pollutants to surface water include some industry-specific sources and those occurring across all types of oil and gas development processes. For example, drilling is a component of most types of gas and oil development. Drilling fluids containing additives and contaminants from geologic sources are by-products for most classes of resource extraction. Storm water runoff from drill sites or contaminated transfer sites provides another avenue for introduction of pollutants to surface waters. Accidental contributions of oil from spills, either at the drill site or during transport, present another avenue for contamination of ground or surface waters. Discharges of wastewater produced during extraction from traditional oil and gas and coalbed methane are sources of oil and grease, dissolved solids, organic compounds, and radioactive compounds. Finally, leaching of contaminants from waste rock associated with extraction of oil shale may contribute dissolved solids and organic contaminants to ground and surface waters.

Although there are numerous recognized avenues for contamination of groundwater or surface waters with pollutants from gas and oil development, few field studies have evaluated the extent of environmental consequences. Of the potential routes of contamination, oil spills have received the most attention. In contrast, wastewater disposal, either in holding ponds or to surface waters, has received relatively little attention. Nevertheless, the practice of discharging wastewater into surface waters, ostensibly for the benefit of fish and wildlife, deserves more attention as a potential source of impairment.

4.2 *Groundwater*

Effects of oil and gas development on groundwater resources include introduction of contaminants from spills, over-pressurized wells, and leaching from surface discharge and storm water runoff. In oil shale and coalbed methane development, dewatering aquifers has potential to reduce groundwater levels, which may ultimately decrease stream flows. Because of hydrologic connectivity to streams, these are important considerations for coldwater fisheries.

Very little data exist to effectively evaluate the cumulative effects of groundwater contamination or depletion on coldwater fisheries. Assessments of water quality in aquifers in association with gas and oil development and investigations of the effects of groundwater depletion should be incorporated into an adaptive management approach for gas and oil development activities.

4.3 *Coldwater Fisheries and Associated Aquatic Life*

Cumulative effects of oil and gas development on coldwater fisheries include the toxicity of either produced waters or spills to fish, food chain organisms, and riparian or shoreline vegetation with functional attributes that support fisheries either directly or indirectly. Numerous laboratory studies referred here confirmed toxicity of common constituents. Nevertheless, the available information did not allow inference on the extent or degree of effects on wild, coldwater fisheries. A lack of field investigations in gas and oil producing regions is the primary data gap that limits the ability to promote the sustainable development of oil and gas in the Intermountain West. In fact, of the 15 publications addressing fish, only two were field investigations (Confluence 2003, Confluence 2004). Moreover, these addressed warmwater fisheries, which have unknown applicability to coldwater environs.

Synoptic field studies examining a suite of biological and physicochemical parameters would be invaluable in evaluating the response of aquatic systems to development of gas and oil. Biological parameters include standard measures that comprise the health of a fishery including species composition and richness, age class composition, abundance, and condition factor (a measure of plumpness). Because some pollutants may bioaccumulate, analysis of concentrations of contaminants in liver and muscle tissues is an important consideration, for both the fishery and human consumption.

Macroinvertebrates and periphyton (attached algae) community analyses have tremendous applicability in evaluating the effect of oil and gas development on aquatic ecosystems. These communities respond predictably to pollutants including organic compounds, salts, and metals. Biological assessments of streams receiving inputs of oil and grease from storm water indicate severe impairment from toxins and nutrients (Confluence, unpublished data). These indicators include near absence of mayfly, stonefly, and caddisfly taxa, high proportions of deformed diatoms, and low richness and diversity of macroinvertebrate and diatom species.

5.0 Conclusions

Based on critical review of publications presented in this annotated bibliography, it is clear that exploration and development of gas and oil has the potential to have negative effects on fisheries, water quality, and associated aquatic life. Numerous laboratory studies confirmed toxicity of many of the pollutants to fish, aquatic life, and riparian or shoreline vegetation. Moreover, several avenues exist for either accidental or permitted discharge of toxic constituents into groundwater or surface waters.

A number of factors present significant obstacles to resource managers in promoting sustainable development of oil and gas in the Intermountain West. A major concern is the protection afforded by current wastewater management practices. Specifically, effluent limits for oil and grease of 10 mg/L may not protect aquatic life beneficial uses such as growth and reproduction of coldwater fisheries (Marty et al. 1997, Woodward et al. 1981). Furthermore, Ramirez (2002) found poor compliance with this effluent limit for oil field wastewater discharges in Wyoming. This combination of a non-protective regulatory framework that may be frequently violated is a major concern.

Another limitation in the ability to protect fisheries, associated aquatic life, and water quality in the face of expanding resource extraction is the lack of field studies evaluating effects on aquatic systems. The literature search for this paper uncovered no peer-reviewed articles evaluating the effects of extraction of energy resources on coldwater fisheries. Conclusions on the potential effects on coldwater fisheries come primarily from laboratory investigations of toxicity and an understanding of the potential risks of pollutant loading related to activities associated with extraction and transport. Field investigations into the extent of pollution associated with exploration and development of gas and oil, combined with evaluations of the response of the aquatic ecosystems should be a research priority.

Table 2 Links to oil and gas related websites.

Regulatory Groups		
Alaska	Alaska Oil and Gas Conservation Commission	http://www.aogcc.alaska.gov/homeogc.htm
Arizona	AZGS, The State Agency for Geologic Information	http://www.azgs.state.az.us/OGCC.htm
California	California Department of Conservation, Division of Oil, Gas & Geothermal Resources	http://www.conservation.ca.gov/DOG/
Colorado	Colorado Oil and Gas Conservation Commission	http://www.oil-gas.state.co.us/
Montana	BLM, Montana/Dakotas Home Page	http://www.mt.blm.gov/oilgas/operation/
	Montana Board of Oil and Gas Conservation	http://bogc.dnrc.state.mt.us/jdpIntro.htm
Nevada	Nevada Commission on Mineral Resources	http://minerals.state.nv.us/programs/ogg.htm
New Mexico	New Mexico Energy, Minerals and Natural Resources Department	http://www.emnrd.state.nm.us/default.htm
	New Mexico Oil and Gas Bureau (Taxation and Revenue Department)	http://www.state.nm.us/tax/ogas/oag_home.htm
Oregon	Oregon Department of Geology and Mineral Industries	http://sarvis.dogami.state.or.us/oil/oilhome.htm
Utah	Utah Division of Oil, Gas, and Mining	http://dogm.nr.state.ut.us/
Wyoming	Wyoming Oil and Gas Conservation Commission	http://wogcc.state.wy.us/
Canada		
Alberta	Alberta Energy and Utilities Board	http://www.eub.gov.ab.ca/BBS/new/Projects/GasBitumenPolicy.htm
British Columbia	British Columbia Ministry of Energy and Mines	http://www.em.gov.bc.ca/Links/OGLinks.htm
	Oil and Gas Commission	http://www.ogc.gov.bc.ca/
Yukon	Department of Energy Mines and Resources	http://www.emr.gov.yk.ca/Oil_and_Gas/default.htm
Northwest Territories	Resources, Wildlife, and Economic Development	http://www.gov.nt.ca/RWED/mog/oil_gas/o_g.htm
Searchable by state for oil and gas well info.	Independent Petroleum Association of America	http://www.ipaa.org
Citizens or Resource Advocacy Groups		
Trout Unlimited		http://www.tu.org/
Theodore Roosevelt Conservation Partnership		http://www.trcp.org/
Wildlife Management Institute		http://www.wildlifemanagementinstitue.org/
Izaak Walton League of America		http://www.iwla.org/
The Wildlife Society		http://www.wildlife.org/
National Wildlife Federation		http://www.nwf.org/
Wyoming Wildlife Federation		http://www.wyomingwildlife.org/
Montana Wildlife Federation		http://www.montanawildlife.org/
American Fisheries Society		http://www.fisheries.org/html/resource/page10.shtml
Oil and Gas Accountability Project		http://www.ogap.org/
North American Grouse Partnership		http://www.grousepartners.org
Industry News		
Gas and Oil Journal		http://ogj.pennnet.com/home.cfm

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