Final Report

Environmental Risk Assessments of Oil and Gas Activities Using National Security and Civilian Data Sources

March 1998

A Report of the Oil and Gas Risk Assessment Subgroup of the Gore-Chernomyrdin Commission's Environmental Working Group

Contributing Organizations

U.S. Environmental Protection Agency

U.S. National Imagery and Mapping Agency

U.S. Department of Energy

Russian Federal Center for Geoecological Systems

Ministry of Defense of the Russian Federation

CONTENTS

CONTENTS (Cont.)

CONTENTS (Concluded)

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

We wish to acknowledge the invaluable assistance of several individuals in the development of the work that this final report represents. Our co-chairs provided valuable leadership and intellectual guidance. Accordingly, we thank Robert Huggett, Aleksey Poryadin, and Peter Robertson for furthering the development of this project. U.S. and Russian contributing authors are listed below:

James K. Andreasen, Peter R. Jutro, Deborah R. Mangis, E. Terrence Slonecker
U.S. Environmental Protection Agency

Brian E. Orlick
U.S. National Imagery and Mapping Agency

Donald A. Juckett
U.S. Department of Energy

Michael A. True
ERIM International, Inc.

Daniel Goodman
Montana State University

Vsevelod V. Gavrilov, Oleg I. Komarov, Sergey N. Rybakov, Oleg V. Zerkal
Russian Federal Center for Geoecological Systems

Sergey V. Ivanov
Ministry of Defense of the Russian Federation

Staff members of YUKOS and Amoco oil companies generously provided data, guidance, and field assistance. Special thanks go to the following U.S. and Russian scientists and officials who were involved in the ongoing development of this effort:

Akimov, S. Aleshin, I. Antipina, E. Arkanov, S. Balashova, Y. Borisenko, B. Carter, C. Chellis, R. Clarke, V. Dolinger, A. Filipenko, M. Frick, V. Gorbenko, B. Hibner, V. Karasev, A. Kasumyan, V. Karasev, Y. Kazantsev, L. Khmarinov, S. King, R. Krieg, V. Makeev, A. Molchanov, T. Murphy, V. Paltsev, V. Pilyugin, A.Pismenniy, J. Quigel, V. Repnev, E. Samarin, D. Spirin, B. Tumasz, Y. Voznesensky, G. Waxmonsky, D. Way, G. Yakovlev, W. Younkin, and C. Zarba

EXECUTIVE SUMMARY

The national security systems (NSS) of Russia and the United States have been used for more than three decades to monitor each other's military and economic infrastructure. These high-resolution imaging systems can provide unique data for assessing a wide range of environmental issues. In 1993, Vice President Albert Gore (USA) and Prime Minister Viktor Chernomyrdin (Russia) held talks on the environmental utility of both nations' classified imagery data. As a result of these meetings, the Environmental Working Group (EWG) was formed in 1995. Its mission was

> "to explore approaches of the two countries to the uses for environmental purposes of unclassified information products derived from classified national security systems as well as procedures for joint studies utilizing such products."

In response to the formation of the EWG, the intelligence communities of both countries worked out procedures and policies whereby unclassified environmental information could be extracted from otherwise classified data. Current EWG projects are using the unclassified maps, diagrams, and declassified imagery to address the following topics: military base cleanup, forestry, arctic climatology, disaster monitoring, and oil and gas development in arctic and subarctic regions.

In this paper, unclassified derived products from the oil and gas project are presented in the form of a Geographic Information System (GIS) database of the Priobskoye oil field in western Siberia. The Priobskoye oil field was chosen as the demonstration site because this recently discovered oil deposit is located beneath the ecologically sensitive Ob River floodplain. Consequently, another objective of the project was to assess the ecological risk of the Priobskoye oil field development using GIS technology with NSS-derived products. Typically, risk assessments are driven by management questions. For this demonstration project, the stressors and receptors were arbitrarily chosen with the intent of reflecting expected management priorities. In one risk assessment example it was found that the risk to rare and economically valuable fish in the event of an oil spill is very seasonally dependent because of the annual flooding of the Ob River. Another risk assessment example—road construction in the Ob floodplain—showed that drainage-sensitive engineering practices can lessen the ecologically destructive ponding that typically occurs when roads are built in a floodplain. At the project management level, risk assessment methodology enables managers to more accurately balance environmental risk with

economic considerations, and it enables local and Federal environmental agencies to participate in pinpointing the most sensitive areas in the oil development region. Finally, the use of ecological risk assessment is proposed as an instrument for regulatory reform.

The conclusions of this study are:

1. Remotely sensed imagery with between 1- and 2-meter spatial resolution (such as that soon to be available from commercial satellite vendors) is an essential ingredient for a reliable GIS-based environmental risk assessment. This type of imagery can lessen the need for expensive and time-consuming field-collected data and can enable risk assessments to be accomplished more quickly, cheaply, and reliably given the ability to extrapolate high spatial detail into broad-area-coverage SPOT and Landsat scenes.
2. Historical imagery data available only from national security sources are essential to developing accurate information on baseline ecological conditions and change over time. The U.S. and Russian approaches to ecological risk assessment constitute complementary methods of optimized environmental management. Both methods provide a comprehensive picture of threat probability for physical and biological aspects of the environment, and both provide an opportunity to jointly evaluate quantitative, temporal, spatial, and economic features of ecological risk.
3. GIS technology—as demonstrated by the U.S.-Russian Priobskoye GIS database—is an excellent tool for managing and displaying data to be used in risk assessments of oil and gas exploration and production activities in fragile arctic and subarctic ecosystems.
4. Example assessments of the risk to fish, waterfowl, and forests from stressors such as oil spills, soil sprays, and road construction showed the interplay of the dynamic Ob flood plain cycle (freeze, thaw, flood, dry) with the receptor critical intervals (spawning, migration, nesting, and new growth).
5. Cooperation between U.S. and Russian government agencies and oil companies will lessen the environmental impact of oil and gas development. Government regulatory agencies and oil and gas companies will be able to use risk assessment methodology to identify and manage risk in an effective fashion.

1. INTRODUCTION

In 1993, Vice President Gore (USA) and Prime Minister Chernomyrdin (Russia) held talks on using classified image data from both nations for environmental purposes. As a result of these meetings, the Environmental Working Group (EWG) was formed in 1995 as an entity within the United States-Russian Joint Commission on Economic and Technological Cooperation (the Gore-Chenomyrdin Commission). Its mission is: “to explore approaches of the two countries to the uses for environmental purposes of unclassified information products derived from classified national security systems as well as procedures for joint studies utilizing such products.” EWG projects were started to address the following topics: military base cleanup, forestry, arctic climatology, disaster monitoring, and oil and gas development in arctic and subarctic regions. The subject of this paper is the oil and gas project: improving environmental risk assessments through the use of national security systems (NSS) data. The purpose of this final report is to describe the direction and progress of the oil and gas project.

1.1. DESCRIPTION OF ENVIRONMENTAL PROBLEMS OF OIL AND GAS DEVELOPMENT

Some of the largest oil reserves in the world are located beneath arctic and subarctic regions. These areas have unique geology, climate, hydrology, vegetation, and wildlife. One significant and unique geologic feature of the arctic is the permafrost layer that underlies most of the terrain. Climatologically, the arctic is characterized by long cold winters and a brief summer growing season. Bogs and other wetlands are common hydrologic features. Many rivers, strongly affected by the annual ice regime, have large floodplains; massive areas are subject to periodic inundation. Vegetation varies from mosses in the arctic tundra to grasses and boreal forests in the subarctic regions; wildlife, such as birds, mammals, and fish, is typically migratory. All of these unique environmental features are subject to disruption by human activity, including oil and gas development. In addition to their effects on natural conditions, oil activities affect the indigenous human population that pursues a subsistence living under these harsh conditions. For these people, activities associated with oil development are often their first interaction with modern industrial society.

Oil and gas development characteristically moves through several phases, from exploration, to development, exploitation, and decommissioning. The direct and indirect effects of oil and gas development on the environment depend on the development stage. The initial prospecting with remote sensors has no harmful impact on the environment. Subsequent seismic surveys can cause surface scarring due to surface traffic. Exploratory drilling, to confirm the oil deposit and determine production engineering details, can begin to contaminate the environment—on an initially small scale—through oil spills, road construction, produced water, and other wastes. Scaling up to development of large oil fields requires construction of infrastructure—roads, pipelines, power lines, temporary housing, and well pads. The road infrastructure can increase sedimentation and change drainage patterns, especially in flood plain areas. Spills and produced water removal during the production stage can cause substantial impact if environmental procedures are not carefully designed and implemented. Effects on air quality from gas flaring and pump sprays are another adverse impact. During decommission, the production wells are abandoned, leaving enduring scars unless the land is reclaimed and revegetated. The social impacts to the indigenous people include those that are directly measurable (food and resource contamination, reduction, or elimination) and those that are less susceptible to measurement (quality of life).

Methods of management and environmental protection during high-latitude oil exploration and production have been improved in recent years. These new methods include better personnel training, more environmentally friendly operational procedures, and improved environmental awareness on the part of top management and operational staff. The procedural framework for environmental management includes environment profiles, environmental impact assessments (preliminary and advanced), monitoring, and auditing.

1.2. JUSTIFICATION OF THE NEED TO DEVELOP ECOLOGICAL RISK ASSESSMENT METHODOLOGY

The worldwide demand for oil is increasing, and there appear to be few alternatives to increasing productivity, even from fragile arctic ecosystems. The existing environmental protection methodology, based on environmental impact assessments, is a step in the right direction but is still largely qualitative and subjective. Risk assessment methodology enables managers to more accurately evaluate the tradeoffs between environmental risk and economic considerations. It enables local and Federal environmental agencies to participate in pinpointing the most ecologically sensitive areas in the oil development region. Environmental issues are complex, and designing an environmental database to support risk assessment is a major and costly undertaking. But the cost of cleanup after an environmental disaster such as an oil spill is enormously greater. Therefore, environmental risk assessment should be included in the initial project planning in order to create oil development plans that minimize environmental impact.

1.3. OBJECTIVE - RISK ASSESSMENTS USING GIS TECHNOLOGY INCORPORATING NATIONAL SECURITY SYSTEMS DATA

The spatial data needed for risk assessment lend themselves naturally to the data management system called GIS (Geographic Information System). In this system the spatial data and their attributes coexist in a database that allows spatial analysis and display of "what if" scenarios, to be effectively and quickly performed. GIS is a promising technology that has had success in engineering, disaster planning, city management, and other disciplines. More accurate and higher fidelity spatial data, such as that provided by national security imaging systems, reduces some of the uncertainty in the risk assessment.

The national security systems of Russia and the United States have been used for more than three decades to monitor and assess each other's militaries, economies, and infrastructures. In particular, the high-spatial-resolution imaging systems can add unique data for assessing a wide range of environmental issues. For this reason, in 1995 the United States declassified and made available to the public more than 800,000 images acquired by its intelligence imaging satellites between 1960 and 1972. This imagery is a permanent record of environmental conditions in large parts of the world and predates Landsat, the first civilian satellite imaging system, by 12 years. Under the auspices of the Gore-Chernomyrdin Commission, special agreements have been reached by the United States and Russia to derive unclassified environmental information products from currently classified NSS imagery and to share these data with the EWG subgroups. In the specific case of the Oil and Gas Subgroup, the unclassified derived products of oil development activities are incorporated into a GIS to form the database from which risk assessments can be produced.

1.4. PARTICIPANTS - U.S./RUSSIAN REGULATORY AGENCIES, INTELLIGENCE AGENCIES, OIL COMPANIES, LOCAL GOVERNMENTS AND ORGANIZATIONS

The Oil and Gas Subgroup of the Environmental Working Group was formed in 1995. Its participants include U.S. and Russian government agencies (regulatory and intelligence) and private industry (Amoco and YUKOS oil companies). A description of the capabilities and interests that each group brings to the risk assessment process is given below.

U.S. Environmental Protection Agency (EPA)

The Environmental Protection Agency is charged with protecting the human health and environment of the United States. In its 25-year existence, the agency has evolved the process of environmental protection from requirements for environmental impact statements to more quantitative risk assessment and management. It brings this expertise to bear on the unique problems of oil and gas development in arctic and subarctic regions.

U.S. Department of Energy (DOE)

The Department of Energy is responsible for Federal energy-related technologies including petroleum, renewable energy, nuclear energy, energy efficiency, and national energy policy. The Department supports the efficient and environmentally sensitive development of natural gas and oil domestically and on a global basis.

State Committee on Environmental Protection (SCoEP)

The SCoEP is the Russian agency charged with enforcing the environmental laws of Russia and suggesting new ones. The SCoEP is interested in ensuring environmentally safe practices in the new oil fields under development in Russia. For example, the SCoEP is actively engaged in improving environmental protection after the initial licensing of oil production facilities.

U.S. Intelligence Community

The U.S. intelligence community has been monitoring the Russian military, economy, and infrastructure with a variety of NSS, including space-based imaging systems, for decades. The intelligence community has worked out policies, procedures, and methodologies whereby unclassified environmental information can be extracted from otherwise classified data. This data is the cornerstone of the EWG analysis structure.

Russian Intelligence Community

The Russian intelligence community has been monitoring the U.S. military, economy, and infrastructure as well. It is reasonable to believe that its NSS imagery record of the United States is more extensive than the U.S. intelligence community's record of the United States, and vice versa. The projects under the EWG have been designed to maximize the use of otherwise unavailable data for the benefit of each country.

Petroleum Advisory Forum (PAF)/Amoco

The PAF is a Moscow-based industry association comprised of the western oil companies doing business in Russia. Amoco is involved in the PAF and it has its own environmental department focused on improving industry standards for environmentally responsible oil development, and it is interested in promoting such practices in Russia. The PAF and Amoco see possibilities for GIS methodology and NSS data to improve measurement of predevelopment oil field conditions and planning for rapid response to emergencies. Amoco offered to help support the activities of this group at a site at which it is cooperating with YUKOS, but Amoco formally works with this EWG project as the chairperson of the PAF Health, Safety, and Environment Committee.

Joint-Stock Oil Company "YUKOS"

Joint-Stock Oil Company "YUKOS," the Russian oil industry participant, is interested in maintaining the environmental integrity of its existing and newly developed oil fields.

2. IMPORTANCE OF NATIONAL SECURITY SYSTEMS DATA TO DEVELOPMENT OF ENVIRONMENTAL RISK ASSESSMENT

The fragile arctic and subarctic ecosystems are important natural resources for both countries and are under increasing pressure for economic development. Both sides agreed that the specific activities of the EWG Oil and Gas Subgroup should be focused on methods to obtain the information and perform the analyses needed to ensure environmental security while exploring economic development. The EWG was given a unique opportunity to derive information from data sources unavailable to the public and to make products that can be shared with the public through the Gore-Chernomyrdin Commission (GCC). The following attributes make NSS data (particularly imagery data) unique and therefore of high value to environmental risk assessment:

1. Historical imagery data, if available for a particular site, can be decades old and provide an irreplaceable and unique record that can serve as a baseline of past conditions. In addition, if historical imagery of a site over multiple dates is available, a reliable time-series analysis can be completed;
2. The high spatial resolution of NSS imagery data can provide "ground truth" in relatively small areas and can aid in the interpretation of coarser-spatial-resolution data such as SPOT and Landsat. The GIS database, and thus the risk assessment, can then be extrapolated to wider geographic areas;
3. NSS imagery data may be the only data available for otherwise remote and inaccessible areas; and
4. The high-detail data that can be derived from NSS imagery markedly improves the reliability of GIS-based environmental risk assessments.

2.1. GIS AND ITS ADVANTAGES FOR PROJECT IMPLEMENTATION

The development of risk assessments inherently requires a significant amount of spatial data concerning the status, extent, and distribution of natural and manmade features. GIS systems provide the tools for storage, retrieval, and analysis of geographic information, and are uniquely suited to integrate multiple layers of information in the complex process of ecological risk assessment. Regarding analysis, GIS technology combines the power of computer cartography with the versatility of relational database management systems to create powerful tools for spatial analysis. GIS explicitly encodes the geographic location of environmental, ecological, and anthropogenic features on or near the Earth's surface. The geographic location of all mapping elements becomes the key to integrating and analyzing all data stored in the GIS system. GIS-based analysis is based on the fundamental concept of multiple layers of information, each explicitly describing an environmental theme (such as forest cover) in terms of cartographic units (points, lines, and polygons), as well as a large number of database attributes, which can be used for powerful geographic and/or information analysis procedures.

GIS technology has evolved from several disciplines, including cartography, remote sensing, geography, and information management, and is in part the result of a mapping automation process that has evolved over the past 20 years. Advancements in microprocessors, computer graphics, imaging, and relational database management systems have made GIS technology a viable and predominant technology for investigating the complexities of ecological systems. Even with these enormous advances, GIS still needs improvement in spatial statistical analysis tools, which are required for risk assessment. Each map feature is tied to a database management system that can record and store a large number of attributes about that particular element. These can be used with information management functions such as Boolean logic (AND, NOT, OR) to perform complex database analysis functions. The cartographic and database management functions can be combined to create whole new maps with the speed and power of modern computer technology.

The development of risk assessments is traditionally based on the use of a large volume of spatial data on the status, scale, and distribution of natural and anthropogenic factors. GIS systems serve as a tool for storage, retrieval and analysis of geographic information, and allow integrating numerous layers with geographic information and data bases during the complex ecological risk assessment process. The use of GIS technologies provides a great advantage for the purposes of comprehensive ecological risk assessment for several reasons. First of all, input data is easy to display and understand. If necessary, GIS technologies allow users to review the required geographic information, perform calibration, delineate an area, and quickly obtain information on a specific site. In this respect, GIS technologies provide invaluable assistance. The second advantage of GIS applications is the ability to add information layers which allows users to determine critical areas of parameter based risk and provides an opportunity to conduct spatial process simulation. Another invaluable factor is the ability to update existing information and add new data to information layers without deleting old data. This aids in reviewing dynamics of processes, monitoring and forecasting of certain situations. Since GIS exist in electronic format, we can transmit and exchange of information rapidly. This facilitates joint research activities and speeds management decisions.

2.2. GIS DEVELOPMENT METHODOLOGY

The goal of the GIS development activity was to create GIS layers that were useful for risk assessments of oil field activities. The Russian and U.S. participants agreed on data layers (e.g., infrastructure, geology, vegetation) to meet this requirement. To support the production of the GIS layers, the data acquisition phase included obtaining and developing charts, maps, data tables (such as chemical and contaminant toxicity testing), civilian images, and NSS imagery of the study site (described in detail in section 4). In addition to archived data, recent imagery was obtained to document the present conditions and the high temporal rate of change in the study site. Following the data acquisition phase, each of the GIS layers was extracted from NSS imagery or from other unclassified data sources. Note that after the GIS information was extracted from NSS data, the GIS layer itself was unclassified even though the source of the GIS layer was still classified. The GIS extraction methodology followed the usual system for GIS data input, including some additional safeguards for the NSS data. From the outset it was intended that NSS data augment other data sources, including civilian satellite data, unclassified maps, research reports, and relevant data compilations.

Because of differences in the U.S. and Russian data, it was anticipated that there would be differences in the GIS layers derived from NSS data. These differences were due to temporal differences of U.S. and Russian NSS data, both in year and season; resolution differences between NSS imagery of each country; and interpretation and digitization differences while extracting the GIS layers. The reconciliation of differing GIS layers was done at a joint U.S.-Russian meeting at which paper maps of each side's GIS layers were compared side by side and overlain on a light table. The U.S. and Russian layers were compared for content and detail. In most cases one of the two layers was obviously superior. That layer was chosen as the base (primary) layer. Then features in the other layer (that were not in the base layer) were added to create a combined U.S./Russian layer. Areas of disagreement, such as the existence and location of some pipelines, were decided by consensus since inspection of the source imagery was not possible. In some cases the existence of features was validated by using the records of a 1996 joint Russian-U.S. on-site inspection. With regard to spatial registration between the Russian and U.S. GIS layers, it was found that even though the UTM grid was agreed upon, the projections used by both sides were slightly different and the control points used by both sides were not identical. The spatial error was found to be a 50-100 meter translation, which was corrected by resampling the GIS layers. After the resampling, each of the layers and sublayers were precisely spatially registered. One of the advantages of this system is that newly acquired information can be easily incorporated into the existing GIS to support monitoring or further risk assessment activities.

2.3. VALUE-ADDED OF NSS-DERIVED PRODUCTS

In the beginning of this section, we enumerated generic benefits of NSS data for environmental analysis efforts such as this one, which involved using GIS as an analytical tool. Elements of this system were derived from NSS data, so as to allow us to better predict adverse environmental consequences of oil exploration. There are four basic ways that NSS-derived products can add value to GIS databases used for environmental risk assessment: (1) National Security Systems provide imagery collected since the early 1960s, a unique baseline data set to compare with current conditions; (2) risk assessment often requires GIS layers at high spatial resolution, e.g., oil field pumps and buildings, which are obtainable only with NSS data; (3) NSS data can provide "ground truth" for broad-area risk analyses based on civilian sensor data; and (4) NSS imagery may be the only data available for otherwise remote and inaccessible areas.

Nevertheless, NSS were designed for use in the national security arena and, despite the national security implications of environmental issues, their use for environmental matters is new and somewhat controversial. Accordingly, it was felt that it would be valuable to more specifically quantify the value added to environmental analysis by NSS. We begin by developing an analytical approach structure. Such a generic approach consists of the following four steps

1. Enumerate the NSS products used (archival material, high-resolution imagery, etc.).
2. For each NSS product used, indicate the best non-NSS source of the same type of information and provide the available resolution (space, time, or accuracy) of each.
3. Rerun the risk assessment using the non-NSS sources in place of the NSS data.
4. Document the difference that results from the different quality and quantity of information inputs, in terms of:
    a. The resulting spatial detail of the locations where risk is higher than the decision-making tolerance.
    b. The resulting temporal detail of the conditions when risk is higher than the decision-making tolerance.
    c. The costs, in frequency of false positive and false negative decisions, resulting under the two data sources.

Examples of decision rules that might be driven by results of a risk assessment are:

The planned activity is precluded wherever (or whenever) the local risk measure exceeds a critical threshold.

Some mitigation investment is required wherever (or whenever) local risk measure exceeds a critical threshold.

A false positive would be a case, for example, in which a decision is made that mitigation action is needed, when in fact it is not. A false negative would be a case where a mitigation action is not triggered, when in fact it should have been. It can be proven mathematically that, on the average, more and better data will result in lower false positive and false negative error rates when the decision rule optimizes the expected costs of the outcome. In other words, on the average the costs of the consequences of wise risk management will be lower if the input information is better. The cost-benefit analysis of the value of the additional information hinges on whether the direct cost of obtaining that information is larger or smaller than the cost savings expected from its use in a decision process that relies on the results of a risk assessment based on that information.

3. ECOLOGICAL RISK ASSESSMENT METHODOLOGY

3.1 PROJECT GOALS AND OBJECTIVES

One of the goals of this project was to demonstrate the benefits of risk assessments to making informed environmental decisions, and to describe the methodology used to conduct a risk assessment. In the process, we compared the methodological approaches of the US and Russian scientists in carrying out a risk assessment, expecting that the underlying scientific logic would be very similar, though the institutional setting might differ. It was our hope that viewing each other's risk assessment methodology applied to a common case study would provide a new perspective, allowing both sides an opportunity to make advances in the theory and practice of conducting and using risk assessments.

Determining ecological risk is a complex process. For instance, the ecological risk from an oil spill is not necessarily proportional to the total spill volume. A spill in the Komi region of Russia in November 1994 was almost five times the total volume of the 1989 Exxon Valdez spill in Prince William Sound, Alaska. But the ecological damage from the Komi spill was less severe because the oil was naturally contained at Komi. Risk assessments produced using GIS environmental databases can quantify the risks of such spills before they occur so that response planning is optimized, and more accurately quantify the possible consequences of oil spills—including geological, hydrological, and meteorological factors—than environmental impact studies alone. Besides improving emergency planning, risk assessments will also enable managers to balance economic and environmental factors during oil exploration, production, and decommission activities.

3.2. INSTITUTIONAL DIFFERENCES IN RISK ASSESSMENT APPROACH

U.S. and Russian risk assessments get used in a different way in their country's respective decision-making process. This difference in purpose may color the methodology slightly, and explain some differences in emphasis. The Russian risk assessment basically is a prospective form of natural resource damage assessment: the risk assessment attempts to predict the environmental cost of the project, and then if the project is approved, the government charges the project the environmental cost in advance. This is essentially a charge for "environmental insurance." The charge to the project is not revised in light of actual subsequent events. There is an important intimate link between risk assessment and risk management. In the U.S., many risk management practices are required to be designed into the project. The risk assessment calculations are then run using the required good risk management practices and any additional risk management practices advocated by the project. In some of the Russian projects, the state-of-the art risk management practices may not be available for all development. The risk assessment can be run using proposed construction and operation practices, and run using state-of-the-art practices, and determine the environmental risk using both scenarios.

By contrast the U.S. risk assessment is used to make decisions about whether a project should move forward, and whether more (or less) environmental safeguards should be developed for the proposed project. The U.S. designs environmental safeguards upfront in a project, and charges against a project for subsequent environmental damage, if any, are evaluated after the fact of that damage, independent of the original risk assessment. In some settings, such as Superfund, a risk assessment might form the basis for requiring the posting of a bond against the chance of a future accident, but that bond could be released at the end of a specified period of time if the accident did not materialize, and the bond would not indemnify the project against later judgments if the cost of an actual accident exceeded the amount of the bond. While risk assessments may provide a rationale for planning risk management, in the US system, the risk assessments often focus on plausible worst cases rather than taking the full effect of extensive risk management into account.

3.2.1 Codification and Institutional History

In the United States requirement for risk assessments is written into a considerable volume of legislation and regulation. There is likewise a significant amount of EPA documentation specifying some of the technical details as well as general guidance on how a risk assessment should be carried out. Much of this documentation is specifically directed at human health risk assessments, since it is acknowledged that ecological risk assessment is at a less formalized stage of development. Nevertheless, this documentation for human health risk assessment does provide a framework for some official guidance of practice, if only by analogy. And there is a draft Ecological Risk Guidelines (U.S. EPA, 1996). Other relevant official, or quasi-official, documents include:

1992 US EPA Exposure Assessment Guidelines
1992 US EPA Risk Assessment Council Guidance
1994 US National Academy of Sciences, Science and Judgment in Risk Assessment
1995 US EPA Policy for Risk Characterization
1997 US EPA Policy for Use of Probabilistic Analysis in Risk Assessment, Guiding Principles for Monte Carlo Analysis

3.2.2. Risk Assessment and Environmental Impact Assessment

Environmental impact assessment (EIA) has been a mainstay of modern U.S. environmentalism. It attempts to provide procedural guarantees that ensure that a broad range of potential impacts of specified activities are identified before those activities are permitted to proceed. In general, EIA is designed to provide an assurance that knowledge of potential consequences of projected activities will be made available to decision makers or placed on the record so that interested parties can better evaluate them. Such EIA exercises tend not to be rigorously quantitative and are generally not legally tied substantatively to an decision process, though there is a procedural requirement that the assessment be carried out and publicized.

Environmental risk assessment, on the other hand, is an attempt at undertaking a quantitative evaluation, with assumptions and calculations available for examination. In health risk assessment, an agreed-upon risk standard, achieved through a standardized computational formula associated with the subsequent decision, is used by governments and other decision makers as a threshold for decision based on the effect of a chemical or an action on human health. Ecological risk assessment is in an earlier stage of development. Ecological risk assessment does not enjoy the relative simplicity of health risk assessment, in which the calculation is simplified by the fact that there is one target organism (humans), and clearly specified endpoints (e.g., cancer, teratogenicity, neurotoxicity). Ecological risk assessment must deal with a broad set of endpoints and processes in a rigorous, quantifiable, and reproducible fashion, in the context of subsequent use of such information by interested parties, and a formal understanding that the outcome of the analysis may serve as an input to a subsequent decision-making process.

3.2.3. Risk assessment and Natural Resource Damage Assessment

In US environmental decision processes there is a mechanism for governments to seek monetary compensation for environmental damage resulting from some activity. To fix a cost on the damage, a Natural Resource Damage Assessment is conducted. This assessment, unlike a risk assessment, is retrospective. It attempts to reconstruct, quantitatively the magnitude of damage that took place. Like a risk assessment, there may be elements of estimation and uncertainty, but the probabilities involved are about fundamentally different events. In a natural resource damage assessment, the uncertainty is about what actually did happen in the past, whereas in a risk assessment the uncertainty is about what might potentially happen in the future.

3.2.4. The Time Dimension in Risk Assessment

Ecosystems exhibit a tendency to return to equilibrium after modest disturbances. Owing to this resilience, many environmental impacts will self-repair after a period of a few years or decades; but more intense impacts, that exceed the natural capacity for recovery, will take much longer to dissipate. This raises a question of how to weigh the expected time to recovery for different consequences considered in a risk assessment.

In U.S. economic analyses it is conventional to weigh differently the costs that are exacted at different times. The weighting is accomplished by a discount rate which depreciates a cost by a factor that is exponential with the time difference between the present and the time when that cost is incurred. Philosophically, this is sometimes justified in terms of the uncertainty about the future. Very practically, it may be justified in terms of the opportunity cost of changing the time of an expenditure, in light of the interest that would be charged in financing that expenditure. In public decision making where a cost-benefit analysis may be mandated, the discount rate that applies is also generally mandated. There is some debate over what is the correct value of discount rate to use for public decision making.

By analogy, a discounting procedure may be applied in risk assessment for converting to a common basis consequences that occur at different future times, or consequences that unfold over a period of time. Discounting will treat as more serious a consequence that occurs soon, compared to the same consequence that occurs later.

3.3 THE RUSSIAN RISK ASSESSMENT MODEL

The Russian side, on the other hand, defines ecological risk as a recognized acceleration of negative processes which could cause disturbance of environmental resilience as a result of anthropogenic impact on the environment**.** Ecological risk is a comprehensive indicator of potential temporal degradation of ecosystems. Ecological risk can vary based on the nature and viability of management decisions during planning and implementation phases of economic activities. An ability of altering ecological risk is based on the knowledge of the most significant elements of the environment that are affected by anthropogenic activities and its ecosystem. Ecological risk occurs every time when there is anthropogenic impact on the development of ecosystems. Therefore, the Russian side considers an ecological risk assessment to be an assessment of environmental impact probability attributable to anthropogenic activities. Such a description corresponds with the modern legal and regulatory basis for the environmental laws of the Russian Federation and mechanisms of their implementation.

Russian ecological risk assessment is based on an assessment of environmental resilience in cases of anthropogenic impact. Resilience is defined as the capability of the environment to recover and clean itself during a stated period of time according to the power and temporal parameters of anthropogenic impact. The point of zero tolerance is a level of disturbance beyond which recovery to baseline conditions (prior to impact) becomes unfeasible. Consequently, high tolerance of the environment determines low level of risk, and low tolerance determines high level of risk.

In this project, the Russian evaluation of environmental tolerance is based on landscape geochemical and hydrogeological zoning. Contours of similar landscape and hydrogeological features provide spatial characteristics of the territory according to the level of pollutant diffusion capabilities. The smaller the diffusion capabilities in a contour, the slower the process of environmental recovery, all other things being equal. Therefore, the longer the effect of the impact at a specific site, the faster an irreversible degradation process can begin. Thus such a contour is classified as a contour with a higher level of ecological risk.

The term "potential" is used in quantitative calculations of ecological risk that is at a lower measure of resilience. Potential is a maximum time period within a certain intensity (specific mass) of impact (e.g., oil spill), after expiration of which an irreversible process of environmental degradation begins. Landscape degradation and disturbance of hydrogeological regime automatically leads to disturbance of biocoenosis and the ecosystem as a whole.

Resilience assessment is a forecast of the possible presence of the most hazardous elements and can be accomplished quite accurately. During the assessment phase, it is necessary to determine predominant factors of anthropogenic impact (the best case scenario includes oil contamination, mechanical infringement of landscape, and ponding or drainage). After such an analysis is complete, it is possible to calculate potential ecological damage and the cost of preventing or remediating it.

Ecological risk assessment assumes that environmental managers will use their best efforts to prevent risk realization. If actions or calculation of indicators of ecological risk are inadequate, such indicators will deteriorate and the risk will need to be recalculated. The monitoring of environmental conditions before, during, and after project development plays a major role in the decision-making process.

A concept of impact is used in determining an ecological risk. It is possible to calculate an impact to the environment from past occurrences. The concept of future impact does not include imminent adverse effects on the environment from previous impacts. An impact might not actually be applied, or might be applied at a smaller or greater level. Ecological risk assessments use an average maximum value of future impact probability that is derived from site characteristics and economic features, e.g., from technological risk (quality of pipes, roads, etc.) and risk of predetermined management decisions (for example, "need to drill right here because it is cheaper and more effective, although impact on the environment could be greater…," etc.).

To this point, traditional Russian ecological risk assessment is based on an assessment of environmental resilience in cases of anthropogenic impact. Resilience is defined as the capability of the environment to recover and clean itself during a stated period of time according to the power and temporal parameters of anthropogenic impact. We would like to clarify the most important factors in determining resilience - the point of "zero" tolerance and the critical value (critical point). The "zero" tolerance can be presently determined only as a term or a point in a chart with certain characteristics. Such a point is determined by the fact that a living component of the environment is absent in this point, therefore environmental degradation is not feasible. Such a point can be classified as an "absolute desert" with undetermined resilience in describing environmental conditions. Although, it is practically impossible to reach such levels in terrestrial conditions.

It is necessary to define critical value of resilience (a point in resilience chart) within the overall resilience classification. A point of resilience critical value exists in a stated (specific) environment (ecosystem) under the conditions of technogenic impact and such a point is determined as a moment of sharp transformation of the environment to a lower level of its development. The return to previous conditions of environmental development is impossible to accomplish if the critical value has been reached.

High resilience of the environment determines low level of risk. Low resilience determines high level of risk. Resilience assessment is a forecast of possible presence of the most hazardous elements and can be accomplished quite accurately. Although, during the phase of formulation of major assumed or existing environmental problems it is necessary to determine predominant factors of anthropogenic impact (in our case, it is oil contamination, mechanical infringement of landscape, and ponding or drainage).

The term "ecological potential" is used in quantitative calculations of ecological risk. Ecological potential is calculated using environmental resilience assessments. Ecological potential is a maximum time period of constant impact provided by a stated mass of stressors, after expiration of which an irreversible process of environmental degradation begins. In addition, it is feasible to determine a time period of critical value for environmental resilience beginning with the moment of completion of special research.

Ecological risk assessments should include the calculation of risk's average maximum value which depends upon site characteristics and the nature of economic activity, i.e., technical condition of economic sites (i.e., quality of pipelines, roads, etc.), and probability characteristics: predetermined management decisions, accidental violation of technological regime (for example, a mistake by an operator), and accidental equipment fault (for example, breakage of a pipeline by an off-road vehicle).

We would like to mention the following aspects of methodology description for ecological risk assessment. Calculation of ecological risk is based on an assessment of conditions of soils, ground, surface and ground waters, and correlation between such factors. Description of landscape features is a comprehensive key to an assessment of correlation between such factors. Such description can be classified as a description of geoecological conditions or geoecological nature of the environment.

Geoecological conditions of the environment represents a basic function of resilience or stability of the environment, an alteration of which causes changes in ecosystem's resilience. For example, changes in chemical and microcompound composition of soils and its ponding would cause changes in species and density of vegetation, replacement of forests with shrubs, and pseudonatural changes in tree species and their subsequent destruction. Such changes would be followed by alteration in bird and animal species and decrease in number of rare species.

Environmental resilience is based on resilience (stability) of geoecological characteristics of a territory which would be affected by specific impacts in the future (such as noise and air pollution). Environmental stability is determined using the main formula of nature - "no food - no life" - in all of its diversity and the mass of its biota components.

Ecological potential is assessed following the description of geoecological conditions and assessment of stability for geoecological conditions in a specific territory. In comparison with the common interpretation of geoecological conditions as environmental conditions of geological environment, we included the description of vegetation in the description of geoecological conditions.

As stated earlier, ecological risk assessment is based on landscape-geochemical and hydro-geological zoning techniques. We should consider the fact that is possible to apply such zoning for the purposes of ecological potential assessment not only to less urbanized areas, but also to highly urbanized megalopolises with certain corrections. Such corrections are related to the fact that within highly urbanized areas such as Moscow, London, and New York, the characteristics of environmental resilience have already passed the critical point once or several times. In such territories, only certain components of the environment and ecosystem should be preserved because natural environmental conditions in fact don't exist in such urban territories. This situation is very similar to the task of preservation of certain animal and vegetation species within such well known preserves as zoological parks. Therefore, nature that exists within (are partially beyond) urban agglomerations could be classified as a pseudonatural biopark. Ecological risk assessment for such urbanized territories should include such techniques as functional zoning which is an additional zoning of a territory for the purposes of improving mankind's living conditions. Such functional zoning methods require additional description that is not provided in this report.

Complex landscape, geochemical, and hydrogeological zoning is performed by dividing a territory into pseudo-similar sites (hereinafter, contours). Contours of similar landscape and hydrogeological features provide spatial characteristics of the territory according to the level and nature of reaction of the environment to technogenic impact, including diffusion capabilities of pollutants that eventually penetrate the environment during economic activities. We would like to note the following aspects of levels and characteristics of environmental response to pollutants. We have considered the situation when pollutants that are characterized by stated impact features (characteristics of potential pollution) presently penetrate into soils or water or could penetrate as a result of economic development. The smaller the diffusion capabilities in a contour, the slower the process of environmental recovery, therefore, the longer the effect of the impact at a specific site, the faster an irreversible degradation process can begin.

Such zoning techniques should also consider the fact that geoecological conditions could be already unstable due to “hard” indicators of biota’s viability, for example related to low indicators of oxygen concentration in water reservoirs or higher levels of mineralization which is extremely important to resilience of geoecological characteristics (stability) of the territory.

3.4. THE U.S. RISK ASSESSMENT MODEL

In the U.S. methodology, ecological risk assessment “evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors” (U.S. EPA, 1992). It is a process for organizing and analyzing data, information, assumptions, and uncertainties to evaluate the probability of adverse ecological effects. As discussed in the proposed Ecological Risk Guidelines (U.S. EPA, 1996), an ecological risk assessment consists of the following steps:

- Describe risk assessor/risk manager planning results.
- Review the conceptual model and the assessment endpoints.
- Discuss the major data sources and analytical procedures used.
- Review the stressor-response and exposure profiles.
- Describe risks to the assessment endpoints, including risk estimates and adversity evaluations.
- Review and summarize major areas of uncertainty (as well as their direction) and the approaches used to address them.
  —Discuss the degree of scientific consensus in key areas of uncertainty.
  —Identify major data gaps and, where appropriate, indicate whether gathering

additional data would add significantly to the overall confidence in the assessment results.

—Discuss science policy judgments or default assumptions used to bridge information gaps, and the basis for these assumptions.

Ecological risk assessment includes three primary phases (problem formulation, analysis, and risk characterization) (Figure 1). Within problem formulation, important areas include identifying goals and assessment endpoints, preparing the conceptual model, and developing an analysis plan. The analysis phase involves evaluating exposure to stressors and the relationship between stressor levels and ecological effects. In risk characterization, key elements are estimating risk through integration of exposure and stressor-response profiles, describing risk by discussing lines of evidence and determining ecological consequences, and preparing a report. The interface between risk assessors and risk managers at the beginning and end of the risk assessment is critical for ensuring that the results of the assessment can be used to support a management decision.

3.4.1. Development and Use of GIS for Natural Conditions and Anthropogenic Impact

The characterization of ecological risk is inherently geographic in nature. The location, extent, and distribution of ecological resources, potential stressors, and their interactions across the landscape is critical to the basic characterization of the landscape and to the overall risk assessment process. Because of this, GIS technology is being used to provide the tools for the storage, retrieval, display, and some of the analysis of spatial information about the risks posed by oil and gas development in the arctic landscape.

In GIS development, a central theme is the creation of multiple layers of cartographic data. Each layer usually has a unique theme that represents some aspect of the landscape. The collection of GIS data layers characterizes both the natural landscape (soils, vegetation, lakes, topography, rivers, geology, etc.) and manmade activities (roads, pipelines, powerlines, buildings, etc.). This collection of data layers provides the information necessary to begin the process of determining the impact of anthropogenic activities on natural resources, and this is the essence of the risk assessment process.

Figure 1

3.4.2. Determination of Major Problems of Interaction Between the Environment and Anthropogenic Factors

Both risk assessors and risk managers bring valuable perspectives to the initial planning activities for an ecological risk assessment. Risk managers charged with protecting environmental values can ensure that the risk assessment will provide information relevant to a decision. Ecological risk assessors ensure that science is effectively used to address ecological concerns. Both evaluate the potential value of conducting a risk assessment to address identified problems. Further objectives of the initial planning process are to establish management goals that are agreed upon, clearly articulated, and contain a way to measure success; determine the purpose for the risk assessment by defining the decisions to be made within the context of the management goals; and agree upon the scope, complexity, and focus of the risk assessment, including the expected output and available resources. Problem formulation, which follows these planning discussions, provides a foundation upon which the entire risk assessment depends. A brief outline of the problem formulation stage follows. A more detailed description of this stage is included in Appendix A.

Problem formulation is the process by which the components of risk assessment are identified and related to each other. The components include stressors, receptors, pathways, exposures, endpoints, and adverse effects. Generally, only those receptors that are valued are considered. The pathways by which the stressor affects the receptor are varied; they can be direct or indirect. The measurements to determine impact are taken at the endpoints. An endpoint is often a valued attribute of the receptor. Because there is uncertainty in this description of a complex situation, the adverse effect can only be described as a probability. Later, there may be an iteration on the problem formulation because the information gathered may suggest a modified risk hypothesis or a new path of exposure. Considering all these components and iterations, it is not surprising that a full assessment may be very costly. An alternative is to perform the assessment in tiers, starting with a simple and inexpensive assessment and working toward a more complex and costly assessment if the situation warrants.

3.4.3. Analysis Phase

The analysis phase, which follows problem formulation, includes two principal activities: characterization of exposure and characterization of ecological effects. The process is flexible, and interaction between the ecological effects and exposure evaluations is recommended. Both activities include an evaluation of available data for scientific credibility and relevance to assessment endpoints and the conceptual model. In exposure characterization, data analyses describe the source(s) of stressors, the distribution of stressors in the environment, and the contact or co-occurrence of stressors with ecological receptors. In ecological effects characterization, data analyses may evaluate stressor-response relationships or evidence that exposure to a stressor causes an observed response.

The products of analysis are summary profiles that describe exposure and the stressor-response relationships. Exposure and stressor-response profiles may be written documents or modules of a larger process model. Alternatively, documentation may be deferred until risk characterization. In any case, the objective is to ensure that the information needed for risk characterization has been collected and evaluated.

The exposure profile identifies receptors and exposure pathways and describes the intensity and spatial and temporal extent of exposure. The exposure profile also describes the impact of variability and uncertainty on exposure estimates and reaches a conclusion about the likelihood that exposure will occur.

The stressor-response profile may evaluate single species, populations, general trophic levels, communities, ecosystems, or landscapes—whatever is appropriate for the assessment endpoints. For example, if a single species is affected, effects should represent appropriate parameters such as effects on mortality, growth, and reproduction, whereas at the community level, effects may be summarized in terms of structure or function depending on the assessment endpoint. The stressor-response profile summarizes the nature and intensity of effect(s), the time scale for recovery (where appropriate), causal information linking the stressor with observed effects, and uncertainties associated with the analysis.

3.4.4. Risk Characterization Phase

Risk characterization is the final phase of an ecological risk assessment. During risk characterization, risks are estimated and interpreted and the strengths, limitations, assumptions, and major uncertainties are summarized. Risks are estimated by integrating exposure and stressor-response profiles using a wide range of techniques such as comparisons of point estimates or distributions of exposure and effects data, process models, or empirical approaches such as field observational data.

Risk assessors describe risks by evaluating the evidence supporting or refuting the risk estimate(s) and interpreting the adverse effects on the assessment endpoint. Criteria for evaluating adversity include the nature and intensity of effects, spatial and temporal scales, and the potential for recovery. Agreement among different lines of evidence of risk increases confidence in the conclusions of a risk assessment.

When risk characterization is complete, a report describing the risk assessment can be prepared. The report may be relatively brief or extensive depending on the nature of the resources available for the assessment and the information required to support a risk management decision. Report elements may include:

- A description of risk assessor/risk manager planning results.
- A review of the conceptual model and the assessment endpoints.
- A discussion of the major data sources and analytical procedures used.
- A review of the stressor-response and exposure profiles.
- A description of risks to the assessment endpoints, including risk estimates and adversity evaluations.
- A summary of major areas of uncertainty and the approaches used to address them.
- A discussion of science policy judgments or default assumptions used to bridge information gaps, and the basis for these assumptions.

To facilitate understanding of assessment results, risk assessors should characterize risks "in a manner that is clear, transparent, reasonable, and consistent with other risk characterizations of similar scope prepared across programs in the Agency" (U.S. EPA, 1995).

3.4.5. Economic Assessment Phase

The economic assessment phase is concerned with the costs associated with the ecological degradation of the environment. Economic assessment is a newer area of study than the purely ecological component. Some economic costs are easy to quantify while others, such as the "quality of life," are less amenable to economic analysis. GIS can help with cost analysis of activities that are quantifiable, such as the cost for transportation of contaminated soil in a remediation effort. That is, the volume of soil and the distance it must be transported are calculable because the GIS is spatially based. The GIS can also reduce the remediation costs by optimizing transportation routes. Another economic cost is for emergency response. In the Komi spill, containment ponds were built for short-term storage. In the Alaskan spill, there were costs associated with immediate and long-term cleanup. In response to the costs of emergency response and remediation the concept of risk reduction was born. Risk reduction methods include enforcement and education. However, risk reduction has its own cost. The benefit of risk reduction is a balance between the cost for each dollar spent on risk reduction and the benefit of less environmental risk.

Returning to the issue of less quantifiable economic costs, we find that the Amoco environmental impact assessment (Yuganskneftegaz and Amoco, 1995) is an example of a method to address economic, social, and cultural issues associated with the proposed Priobskoye development plan. That is, in addition to the economic costs of environmental degradation caused by the oil field development, there are also economic, social, and cultural impacts to the resident population. In the Amoco study of the Priobskoye region the following plan for economic assessment and remediation was used:

1. Identification of economic, social, and cultural issues;
2. Preparation of a baseline profile (existing conditions of the environment);
3. Evaluation of probable changes to the social, cultural, and economic conditions; and
4. The development of mitigative measures to minimize the potential negative impacts.

Based on the experience of the EWG Oil and Gas risk assessment study, the inclusion of better data in the GIS format can improve the quality and reduce the cost of economic impact studies.

3.4.6. Risk Control and Management Phase

After the risk assessment is completed, risk managers may consider whether additional follow-up activities are required. Depending on the importance of the assessment, confidence in the assessment results, and available resources, it may be advisable to conduct another iteration of the assessment in order to facilitate a final management decision. Ecological risk assessments are frequently designed in sequential tiers that proceed from simple, relatively inexpensive evaluations to more costly and complex assessments. Initial tiers are based on conservative assumptions, such as maximum exposure and ecological sensitivity. When an early tier cannot sufficiently define risk to support a management decision, a higher tier that may require either additional data or applying more refined analysis techniques to available data may be needed. Higher tiers provide more ecologically realistic assessments while making less conservative assumptions about exposure and effects.

Another option is to proceed with a management decision based on the risk assessment and develop a monitoring plan to evaluate the results of the decision. For example, if the decision was to mitigate risks through exposure reduction, monitoring could help determine whether the desired reduction in exposure (and effects) was achieved. Monitoring is also critical for determining the extent and nature of any ecological recovery that may be occurring or for detecting risk exceedances that merit early intervention. Experience obtained by using focused monitoring results to evaluate risk assessment predictions can help improve the risk assessment process and is encouraged.

Communicating ecological risks to the public is usually the responsibility of risk managers. Although the final risk assessment document (including its risk characterization sections) can be made available to the public, the risk communication process is best served by tailoring the style of communication to a particular audience. It is important to clearly describe the ecological resources at risk, their value, and the costs of protecting (and failing to protect) the resources (U.S. EPA, 1995). The degree of confidence in the risk assessment and the rationale for risk management decisions and options for reducing risk are also important.

Management goals for a risk assessment are established by risk managers but are derived in a variety of ways. Significant interactions among a variety of interested parties are required to generate agreed-on management goals for the resource. Public meetings, constituency group meetings, evaluation of resource management organization charters, and other means of looking for management goals may be necessary. Diverse risk management teams may elect to use social scientists trained in consensus-building methods. Even though management goals derived in this way may require further definition, there is increased confidence that these goals are supported by the audience for the risk assessment.

Regardless of how management goals are established, goals that explicitly define which ecological values are to be protected are more easily used to design a risk assessment for decision making than general management goals. Whenever goals are general, risk assessors must interpret them into ecological values that can be measured or estimated and ensure that the managers agree with their interpretation.

Risk assessments may be designed to provide guidance for management initiatives for a region or watershed where multiple stressors, ecological values, and political factors influence decision making. These risk assessments require great flexibility and breadth and may use national risk-based information and site-specific risk information in conjunction with regional evaluations of risk. As risk assessment is more frequently used to support landscape-scale management decisions, the diversity, breadth, and complexity of the risk assessments increase significantly and may include evaluations that focus on understanding ecological processes influenced by a diversity of human actions and management options. Risk assessments used in this application are often based on a general goal statement and require significant planning to establish the purpose, scope, and complexity of the assessment.

Part of the agreement on scope and complexity is based on the maximum uncertainty that is acceptable in whatever decision the risk assessment supports. The lower the tolerance for uncertainty, the greater the scope and complexity needed in the risk assessment. Risk assessments completed in response to legal mandates and likely to be challenged in court often require rigorous attention to acceptable levels of uncertainty to ensure that the assessment will be used in a decision. A frank discussion is needed between the risk manager and risk assessor on sources of uncertainty in the risk assessment and ways uncertainty can be reduced (if necessary) through selective investment of resources. Where appropriate, planning could account for the iterative nature of risk assessment and include explicitly defined steps or tiers. Guidance on addressing the interplay of management decisions, study boundaries, data needs, uncertainty, and specifying limits on decision errors may be found in EPA's guidance on data quality objectives (U.S. EPA, 1994).

3.5 EVOLUTION OF METHODOLOGICAL APPROACH

In general we have based our risk assessment approach on the model proposed in the draft guidance document for ecological risk assessment (U.S. EPA, 1996), but the very conduct of this exercise has allowed us to reexamine certain assumptions and work toward the further refinement of elements of the guidance document itself. We found it helpful to go somewhat beyond that document in tightening our definition of risk and formalizing the relationship between risk and uncertainty.

The Draft Guidance Document (U.S. EPA, 1996) proposes that a review and summary of uncertainty be the final step in a risk assessment. This invites treating analysis of the uncertainty as separable from the quantification of the risk itself, in a way that could reduce the usefulness of risk assessments to the decision process.

Note that in ecological applications it is almost inevitable that the uncertainties with respect to models and parameters will be quite high. Our example risk assessment is no exception in this regard. What is a decision maker to conclude from a careful and detailed risk assessment that, in its final section, states that there are large uncertainties in the analysis just presented?

- Ignore the uncertainty statement and accept the results of the risk characterization at face value?
- Dismiss the risk assessment "because it is too uncertain"?
- Ask the analysts to provide a "best estimate" of the risk, and accept that characterization at face value?
- Ask the analysts to provide a "worst-case estimate" of the risk, and then accept that characterization at face value?

All these options have a ring of plausibility, and experienced practitioners are doubtless aware of past instances where each came into play. But each leads to quite different implicit or explicit characterizations of the risk, so they cannot all be correct. This would seem to leave too much discretionary latitude for the influence of subjective elements in the conduct and interpretation of an ecological risk assessment.

It would be helpful if risk assessment practice removed this potential source of ambiguity by integrating the "uncertainty analysis" into the risk characterization itself. In this chapter we explain how we approached a rigorous, quantitative integration of uncertainty analysis in our risk characterization. This had later implications for our understanding of risk tolerance and uncertainty tolerance as they bear on risk management decisions that may be made as the result of a risk assessment. This also has implications for the way we propose to quantify the value of NSS data in our risk assessment, as discussed in section 2.3.

3.5.1. What Is "Risk"?

Formally, a "risk" is a product of the probability of an undesired outcome multiplied by the severity of that outcome, summed over the range of possible undesired outcomes. This is the standard definition of risk in decision theory. See the entry on "Decision Theory" in the Encyclopedia of Statistical Sciences (Kotz, Johnson and Read, 1982). This definition of risk applies as well in insurance calculations, economic analysis, health risk assessment, or ecological risk assessment.

Under this definition, the "probability of outcomes" is a probability distribution. The spread of the distribution represents the uncertainty as to which outcome actually will occur. Since the probabilities from this distribution are multiplied by measures of severity of outcome, and then summed to calculate the total risk, the uncertainty is part of the risk. If the outcomes were not uncertain, we would not call it risk, we would just call the analysis a prediction.

The total uncertainty reflected in the spread of the probability distribution arises from two sources: inherent randomness in future processes and imprecision in our knowledge of how to model those processes. Both sources of uncertainty affect the risk in exactly the same way, so there is no point to separating the two when calculating the risk, and there is nothing to be gained from attempting to remove them from the risk characterization.

This perspective is not new. It was recommended 7 years ago in application to environmental risk assessment (Finkel, 1990). In the intervening years, one component of this approach—simulation of probability distributions for uncertain parameter values in order to propagate the effects of the uncertainty through the risk calculation—has become fairly common in risk assessment, and is generically called "Monte Carlo" (but that term has much broader meaning outside the risk assessment community). A formal approach to quantifying the uncertainty in parameter values is not as common. In recent years a substantial literature has appeared that could contribute to facilitating practical implementation of a formal and rigorous approach. Two important developments are better understanding of empirical and hierarchical Bayes methods to circumvent the problems associated with subjective theories of probability, and new computational techniques that make the probability calculations much easier. Both are reviewed in Carlin and Louis (1996). Goodman (1997) has shown how these techniques can apply to calculation of risk of population extinction in an ecological risk assessment.

The alternative of treating the uncertainty analysis and risk characterization separately is quite unsatisfactory. If risk as we define it is probability of adverse outcome, weighted by some measure of how adverse that outcome would be, and then summed over the spectrum of outcomes, "uncertainty" must already be factored into the probability. If the uncertainty has not already been taken into account, then the probability is wrong and the risk assessment is wrong. If the uncertainty has already been taken into account in the probability, separating the consideration of uncertainty creates opportunities for mistakenly using the uncertainty twice.

3.5.2. Re-Evaluating the Relation of Risk to Risk Management

In decision making there is ideally a set tolerance for risk. This tolerance applies regardless of how much of the risk is due to uncertainty from incomplete data, uncertain model parameters, or uncertain outcomes of future random processes. If the risk is too high, the decision maker is committed to select some action to address it. If the risk is low enough, the decision maker may proceed without specifically taking action to address the risk.

When the calculated risk is too high, then the subsequent decision of what to do about it will require knowing the magnitudes of the contributions of various sorts of uncertainty to the total risk. The decision may seek to reduce the risk through management actions to control the feared outcomes, through collecting additional data and then recalculating the risk on the basis of new data and determining whether the risk is still too high, or through some combination of more data collection and control of outcomes.

The tradeoff between the management action to control outcomes and choosing instead to collect more data ("to reduce uncertainty") is essentially a matter of cost-benefit analysis, not a policy call: sometimes the cost of data is so high relative to its information content that it is more rational to accept the uncertainty and by default select the management action even though there is some probability that it is not actually necessary; in other circumstances the cost of new data is so low, and the value of new data is so high, that the choice definitely is to collect more data. Either way, what is being controlled is risk, and uncertainty appears in the equation only as a contributing factor in the risk.

3.5.3 How Do Data Quality and Quantity Affect Risk?

A risk calculation is not just a model prediction, and so a real risk assessment will behave rather differently from a simple predictive model as its information input is reduced. Indeed, a simple predictive model may well predict a more favorable outcome when it is given less detailed or less precise input information. That is because the model prediction is a single scenario: the best estimate of the outcome. Furthermore, these kinds of models have "out of sight, out of mind” behavior. With less detailed input information, the model will default to assumptions of intermediate input values and will therefore deliver an intermediate output prediction. An example would be the way a kriging model defaults to the sample average when there are no predictor data close enough to the location being predicted. Obviously, this would not be satisfactory for a risk assessment, because our ignorance of the input values does not really make the risk go away.

The way risk assessment takes account of our uncertainty about input values is to represent every uncertain input as a probability distribution. The greater our uncertainty about the input, the broader that distribution. Now, the uncertainty about inputs gets propagated through the prediction component of the risk assessment. The output of the risk assessment is also a probability distribution, showing the distribution of outcomes. The greater the uncertainty about inputs, the greater the uncertainty about outcomes. The uncertainty about outcomes is reflected in the spread of the probability distribution that describes the result. If there is little uncertainty, the probability distribution is concentrated over a narrow range of outcomes, and then the acceptability of the risk depends merely on whether the outcomes in that narrow range are themselves in a range that we consider acceptable.

But if there is great uncertainty, the probability distribution is spread over a broad range of outcomes. If the spread is great enough, a considerable portion of the distribution can “spill over” into a range of unacceptable outcomes, even if the peak is centered over outcomes that are acceptable. This would describe a situation where the “best estimate prediction” is an acceptable outcome, but the risk is still unacceptable because the uncertainty leaves too high a probability of outcomes that are far from the best estimate.

In very conventional applications of statistics to risk calculations, the uncertainty about inputs is factored into the calculation through the use of confidence limits. For example, at a hazardous waste site, the decision about whether a given unit needs to be remediated may depend on whether the upper 95% confidence limit of the average concentration of containment exceeds some tolerance level. Use of the upper 95% confidence limit factors in the uncertainty. The greater the uncertainty (owing to small sample size or variability among the sample values), the higher the upper 95% confidence level will be above the sample average. In this way, the uncertainty exerts a kind of penalty in the decision process, forcing a greater margin of safety as the uncertainty increases. (This is not necessarily the best way to take uncertainty into account in a risk decision process, but it is one that many people are familiar with, and it is sufficient to illustrate the point.)

In a similar way, we might consider a map of our oil development site and ask what portions of the site should be off limits to road construction because the risk is “too high.” If our input information were of low resolution, a good deal of the off-limits area would be so classified only because our uncertainty about those locations was so high that the equivalent of the "upper 95% confidence level" would spill over into the range of unacceptable values. Basically, the map would contain a lot of gray areas that would be classified as high risk. With better input information (more spatial resolution, more precision) many of the gray areas on the map would be resolved into black and white. In the black and white areas the predictions are more certain, and some of the gray area that was previously classified as high risk because of the uncertainty will be reclassified as low risk, and more of the remaining areas that are still classified as high risk will be so classified because of a reasonably secure prediction that the outcome there really will be unacceptable. The high-risk gray area of the map shrinks as the input information improves.

3.6 SYNTHESIS

The U.S. and Russian approaches to ecological risk assessment constitute complementary methods of optimized environmental management. The differences which we encountered are largely due to institutional context rather than scientific framework. Since the underlying definition of risk is the same in both cases, and since that definition is essentially mathematical, it is natural that the scientific approach on both sides is much the same. It is also natural to expect that as the science itself evolves and becomes more rigorous, the scientific approaches will continue to converge even further.

The U.S. method evaluates specific risks of impact from a certain type of anthropogenic adverse effect on a specific living object and subsequently, specific consequences for the ecosystem. The Russian method assesses the risk of developing a cause for a specific adverse factor and minimizes potential threat. Both methods provide a comprehensive picture of threat probability for lithotechnical, geoecological, and ecosystem integrity of the environment, and both provide an opportunity to jointly evaluate quantitative, temporal, spatial, and economic features of ecological risk. An important factor in ecological risk assessment methodology is the task of minimizing the role of subjective and qualitative elements. Rigorous quantitative assessments are more useful to planners, managers, government officials, and politicians in their routine activities and decision-making process, as well as in planning of economic and environmental protection activities.

4. DEMONSTRATION TEST SITE - PRIOBSKOYE OIL FIELD

4.1. PRIOBSKOYE OIL FIELD - REASONS FOR SELECTION OF THIS REGION

Western Siberia is Russia's greatest oil production region, accounting for 60% of Russia's oil. The Priobskoye deposit is one of the more recent finds (1985), which could be further commercialized in the near future. A proposed project plan is a phased oil field development that could recover 578 million tons of oil over 58 years. There are presently more than 500 wells on 26 pads. What is unique about the Priobskoye deposit is that a substantial part of it is located under the floodplain of the Ob River, east of Khanty Mansiysk and 100 km west of Neftyugansk. The Ob is the longest river in Russia (5300 km); it drains 2,600,000 square kilometers and it empties into the Arctic Ocean (see map in Figure 2). Priobskoye was chosen as the demonstration site for a combination of these factors: imminent licensing activity, floodplain ecological sensitivity, and potential arctic involvement in an oil spill situation.

4.2. PRIOBSKOYE FIELD STUDIES - RUSSIAN, JOINT U.S.-RUSSIAN, AND AMOCO

The Federal Center for Geoecological Systems (FCGS), a Russian research organization with wide experience in environmental studies, conducted on-site observations and measurements in September 1996 in order to verify third-party data from previous studies that was included in the Priobskoye oil field GIS. The in-situ data included:

1. Ground granulametric composition, chemical composition, and composition of ground microcompounds from shallow boreholes along three profiles in Site 1 (31 samples)
2. Surface water characteristics—conductivity, salinity, mineralization, and temperature (10 isolated points and 3 streams)
3. Microcompound and organic compound content of in-situ water samples (7 samples)

A joint U.S.-Russian tour of the Priobskoye region was conducted in September 1996. The activities included meetings and talks with local environmental officials, a tour of a pipe-coating facility, an aerial survey of the left-bank production facility and a ground survey of the Balanskaya tributary. Extensive photos and videos were taken by the participants. As a result of the trip, discussions of joint field work were discussed whereby the techniques used by both sides could be compared.

Figure 2

Amoco has been involved in the Priobskoye area since 1991. In 1993 Amoco was chosen to be the foreign partner in the development of the Priobskoye oil field. In conjunction with its bid and financing proposals Amoco has conducted extensive talks with local people, government regulators, and Russian partners to identify environmental concerns. In its Draft Environmental Impact Statement conducted to meet international lending institution requirements (Yuganskneftegaz and Amoco, 1995) Amoco included extensive field studies of wildlife, fisheries, vegetation, soils, and water. Amoco also produced a socioeconomic profile of the local communities. Amoco provided these data for the use of the Oil and Gas Subgroup.

4.3. REMOTE SENSING DATA SOURCES - CIVILIAN AND NSS

Civilian and NSS remote sensing systems both contribute input data to the GIS by identifying and locating oil infrastructure, outlining water bodies, characterizing vegetation, and delineating wetland and flood boundaries. Figure 3 is a sampling of data of the study area taken with the various sensors. In addition to GIS production, remotely sensed data is used to monitor changes in order to validate the risk analysis. Recall that the Priobskoye oil field was discovered in 1985 and the development on the left (south) bank ensued shortly thereafter. Imagery acquired after 1988 shows the effects of the initial oil field development. An example of change detection using Landsat data is presented below.

Landsat

Landsat is a multispectral sensor that has two versions: MSS and TM (thematic mapper). Although their bands are slightly different, they can be analyzed together for change detection. In particular, their spectral bands allow studies of changes in lake productivity to be performed. These lakes and corresponding wetland areas are critical habitats to numerous fish and other species and their continued health is fundamental to the ecological integrity of this region.

One of the primary issues in lake water quality is the effect of potential oil deposition on lake productivity. The deposition could be from airborne, surface, or groundwater fugitive oil emissions. It is assumed that oil deposition would have toxic effects on the lake ecosystem in the form of decreased oxygen availability, decreased light penetration, and reduced phytoplankton production. Any of these could have drastic effects on the overall lake ecosystem quality and trophic status.

Figure 3

Measurements of phytoplankton biomass are commonly used to assess the trophic status of lakes and monitor responses to nutrients (George 1997). This is often accomplished by taking *in situ* water samples and extracting the photosynthetic pigment, chlorophyll a, with laboratory methods (George 1997). However, Chlorophyll a can also be measured by multi-spectral remote sensing techniques and these techniques have been used successfully in a number of applications (Bukata et al, 1985, Ramsey and Jensen 1990, Ramsey 1992, George 1997).

Multi-spectral remote sensing methods are based on the fact that phytoplanton, containing chlorophyll a, strongly absorbs energy in the blue and red regions of the electromagnetic spectrum, and reflects energy in the green part of the spectrum (Lo, 1986). By using a basic green/blue band ratio technique, many research applications have successfully correlated *in situ* measures of phytoplankton biomass with data derived from data acquired multispectral remote sensing systems. Successful applications have used data from the CZCS, Landsat TM and Landsat MSS. However, these methods rely on simultaneous *in situ* phytoplankton measures for calibration. In the Priobskoye study area this type of measurement was not performed at the time of the Landsat TM data collection. Therefore, two other techniques were used to assess potential differences in lake productivity in this area.

The first technique used a simple 2/1 band ratio from 1984 and 1996 Landsat Thematic Mapper scenes that were acquired for this study. Since airborne oil deposition is not likely to travel long distances, it was assumed that oil effects on lakes would be restricted to areas surrounding the specific oil production sites. Since the TM scene covers an extensive area of landscape, and represents before and after periods of oil activity in the area, any adverse affects on water quality are likely to be restricted to areas surrounding the oil production areas. Green-blue band ratios from both the 1984 and 1996 data showed no significant differences in the band ratio signature from any lakes located throughout the TM scenes, except for areas where there was a significant haze problem in the 1984 imagery and one small lake in the southeast part of the scene.

The second method utilized was a Change Vector Analysis (CVA) technique, which is a radiometric change analysis algorithm that uses multiple dates of geometrically registered and radiometrically corrected imagery (Johnson et al 1997). CVA utilizes n-dimensional multispectral imagery analysis to produce two fundamental statistics from the radiometric comparison of the multiple date images; change direction and change magnitude. These two statistics, when mapped on a Cartesian coordinate system, essentially reduce multiple bands and multiple dates of imagery into a two-dimensional 'change space'. This technique has the advantages of including all multispectral bands in the change determination and can detect changes in both the actual land cover as well as in subtle changes in condition.

This CVA technique was applied to the TM data in the overall region of the oil and gas study. Again, very few significant changes in the lake reflectance were noted throughout the greater oil and gas production area and the overall TM scene in general. One small lake in the extreme eastern section of the study area (see Figure 4) appears to have been impacted from sedimentation, most likely from adjacent pipeline and/or tank construction activities. This conclusion was based on the observation of new construction in the area and the fact that this was the only lake where any significant change could be detected. To better validate this conclusion, a statistical comparison of natural fluctuations (using many remote and undisturbed lakes) would show whether the observed change was statistically significant. This is another area where NSS data can help validate the civilian change detection data for monitoring pre-existing conditions and regulating compliance.

SPOT

SPOT has two operational capabilities. The panchromatic channel is a single-band 10-meter resolution sensor. It has stereo capability, but its 10-15 meter elevation accuracy is of limited value over the flat flood plain. The multispectral sensor on SPOT is similar to Landsat, but its operational period is more limited for change detection work. The 1995 panchromatic image of the study area (Figure 3) has sufficient resolution to detect pads and pipelines in the developed left-bank region. Until the new generation of high resolution civilian sensors are launched SPOT panchromatic images are the highest resolution civilian satellite images routinely available.

AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) has been a constant component of the U.S. NOAA weather satellites. The coverage is daily and the resolution is 1.1 km. The Ob River floodplain is wide enough that it is resolved on the low-resolution AVHRR images. This sensor is a capable of monitoring the ice-blocked northern region of the Ob which causes the extensive flooding at the Priobskoye location. Examples of 1996 AVHRR data from the study area are shown in Figure 5. The April 21, 1996 image shows the snow-covered flood plain which stretches from the upper left to the lower right in the image. By the first of June, 1996, the snow has melted and the false colors from AVHRR bands 2, 5, and 7 show the vegetation (red) and flood conditions (dark blue).

Figure 4

Figure 5

Other Civilian Sensors (SSM/I, ERS-1, JERS-1, Radarsat)

The Special Sensor Microwave Imager (SSM/I) senses microwave radiation emitted from the earth's surface (i.e., brightness temperatures) at four frequencies, 19.3, 22.2, 37.0, and 85.5 GHz, with vertical polarization at 22.2 GHz and vertical and horizontal polarizations at the other three frequencies. The spatial resolution of the SSM/I is approximately 25 km at 19.3, 22.2, and 37.0 GHz and 12.5 km at 85.0 GHz. The active portion of the SSM/I viewing area covers a swath of 1500 km. SSM/I allows snow coverage and depth to be monitored on the spatial scale of the entire Ob River basin. Snow depth could potentially be monitored using algorithms calibrated with *in situ* data.

The active radar sensors, ERS-1, JERS-1, and Radarsat, are all-weather sensors that can detect spills during the flood season because of the oil-caused damping of wind-generated waves which changes the radar reflectivity. Active microwave sensors are also used extensively for ice monitoring. ERS-1 data has been used to track the ice floes in Ob Bay. This is important because the time of ice break-up at the mouth of the Ob River determines the flood release in the middle course of the Ob. Flooding has also been tracked on the Ob using ERS-1 data.

National Security Systems

As agreed to by Vice President Gore and Premier Chernomyrdin, the purpose of the EWG is to examine using any type of national security data acquisition system—space-based, airborne, oceanographic, or *in situ*—and derive unclassified products from its data. Because of the remote, inland location of the Priobskoye site, imaging sensors (both space-based and airborne) fulfilled the above directive for this project.

Other Data Sources—'*In Situ*' and Laboratory Studies

In addition to remotely sensed data, risk assessments require '*in-situ*' and laboratory data in order to adequately describe the stressor, receptor, and the environment (natural and man-made). In particular, the risk calculation requires the probability of the stressor occurrence (such as a spill), the fate of the stressor (e.g. petroleum products) in the environment, and the stressor's effect on the receptor. The probability of spill occurence requires engineering construction data and failure rate data. Although we have found that the Internet greatly facilitates collaborative projects by making time sensitive data available and communications rapid, we have also found that some data (e.g. pipeline leak probability) does not exist on the Internet. For instance, it is not available from the American Petroleum Institute website. There is some useful '*in situ*' environmental data available on the Internet which is helpful for determining the fate of the stressor. This includes meteorological and river discharge data from the World Meteorological Organization. Even after the stressor fate and transport is determined, its effect on the valued organisms or ecostructures are generally only available from laboratory studies although field data from similar stessor occurances is useful validation data. A useful source for stressor effects on fish is the EPA's toxicology tabulated data available from the EPA Duluth WEB site.

4.4. DETAILED SITES AND REASONS FOR SELECTION

The Priobskoye development, being in the floodplain of the Ob, could potentially affect a wide area because of the annual flood and the discharge of the Ob and its tributaries. An overview area was chosen to get a regional viewpoint and later to extend the risk assessment to the regional area. There is also a significant temporal aspect because the proposed development plan is in incremental phases. To examine the effects of past, present, and future development activities in the region, three smaller sites within the larger overview area were chosen for closer examination of ecological risk. A description of the sites and the reasons for their selection follows.

<u>Overview Area - (60° 40' to 61° 25' N - 69° 30' to 70° 45' E)</u>

The overview area includes portions of the Ob and Irtysh Rivers, their floodplains, and an upland marsh area between them. The Ob River is the longest river in Russia and its floodplain is up to 20 km wide. In the central region is a marsh and pine-wooded area that includes many lakes and tributaries to the two rivers. The overview area encompasses parts of the northern and southern license areas of the Priobskoye deposit. The northern license area (including Sites 1 and 3) is being developed first. The southern license area (including Site 2) will not be developed in the near future.

<u>Site 1 - (61° 07' to 61° 15' N - 70° 04' to 70° 21' E)</u>

Site 1 is composed of two major regions. The northern two-thirds of the site includes the Ob River floodplain. The topography of the floodplain is very flat, sand is the predominant soil, and there is intense sedimentation due to the annual flooding. The flooding produces shallow lakes, called sors, which are very productive fish areas. The primary vegetation in the floodplain is grass. The southern one-third of Site 1 includes a terrace above the floodplain. It is composed primarily of marsh and forest. Oil development has begun in this area, making it a choice for studying the effects of existing development as well as near-term development.

Site 2 - (60° 50' to 60° 58' N - 69° 39' to 69° 56' E)

Site 2 is located on the right bank of the Irtysh River, 30 km from its confluence with the Ob. Its geology and hydrology is similar (but not identical) to Site 1. To the east of the Irtysh floodplain is a terrace that includes many lakes, tributaries of the Irtysh, sphagnum marsh areas, and pine/birch forest. The soil is sandy-loamy of two types: podzol in well-drained areas and peat/permafrost in badly drained areas. This area was selected because it is not scheduled for development in the near future, although is does contain oil deposits and may be developed later.

Site 3 - (61° 16' to 61° 24' N - 70° 19' to 70° 36' E)

Site 3 is located to the northeast of Site 1 on the right bank of the Ob River. This site was selected for three reasons. First, it could be developed in the near future (3-5 years). Second, it contains a region of high economic value–the Balanskaya River is a major fish overwintering site. That means that the fish concentrated in the river during the winter are at high risk from oil spills. Third, it will give an opportunity to test the risk assessment algorithms using multiple sites (e.g. if Site 3 has an oil spill, then what happens to Site 1 which is downstream from Site 3).

4.5. ECOLOGICAL RISK ASSESSMENT ALGORITHMS - DESCRIPTION OF APPROACH

4.5.1. Problem Formulation

Both sides agreed that the overall problem formulation was: "To develop the oil and gas reserves of the Priobskoye region in an environmentally and economically sound manner." In meetings with representatives of the oil companies (YUKOS and Amoco) and the Russian environmental authorities the members of the EWG proposed particular issues (including stressors and receptors) that would be addressed in this risk assessment. The group addressed receptors of value (e.g., upland forest, fisheries, migratory animals) and stressors of interest (oil spills, road construction, etc.). Recognizing that it would not be able to address all of the issues, the group chose a subset of stressors and receptors to stimulate further discussion and to illustrate the use of the risk assessment process. Table 1 summarizes the chosen stressors and receptors.

Table 1. Stressors and Receptors Chosen for the Study

Stressor	Valued Resources			
	Fish	Water Quality	Waterfow l	Forest
Road construction	x	x	x	
Pipeline breaks	x	x	x	
Oil spray		x		x

Road construction may affect all of the resources through either direct habitat destruction or by indirect effects such as increased ponding, flood alteration, and the release of sediments into the water. Increased sedimentation may degrade water quality by decreasing the amount of light penetrating the water column, filling the interstitial spaces in the gravel of the stream bottom, or directly smothering fish eggs. These actions may directly affect population levels of fish or may affect the habitat of important food resources. Waterfowl may be impacted indirectly through a reduction of food sources or by impairment of their ability to find food because of increases in turbidity.

Pipeline breaks may release large quantities of oil directly into the water if a break occurs at a stream crossing. If a break occurs on land or in a buried section of pipe, impacts will depend on terrain features and whether or not the released oil reaches the water. There are several routes of exposure of waterfowl to the spilled oil. The birds may directly contact the spray and ingest oil while preening their feathers to remove it, or they may be impacted through the ingestion of oil while feeding. Death of the birds may result from direct toxicity of the oil or by secondary effects caused by the loss of body heat because the feathers lose their insulation property. If the oil spill reaches water bodies, fish may be impacted through direct toxicity of the water-soluble fraction of the oil, by impact to the respiratory surfaces of their gills, or indirectly by a reduction in the availability of food. With respect to water quality, severe impacts often occur when heavy equipment is brought in during the cleanup operations and allowed to operate in the stream channel.

Oil spray from the production wells and oil/water separators coats the surfaces of the forest trees, inhibiting oxygen transfer and retarding growth. Coating during bud or seed production times is especially harmful. Oil spray may have direct effects on water quality if the oil enters the water directly or is washed off the land surface into the water.

4.5.2. Development of a Conceptual Model

A simple model of the relationship between the stressors and impacts for the Ob River is illustrated in Figure 6. Several benefits are derived from developing a conceptual model. Conceptual models highlight what we know and don't know and can be used to plan future work, and the process of creating a conceptual model can be a powerful learning tool. In addition, the models can be powerful communication tools because they provide an explicit expression of the assumptions and understanding of a system that others can evaluate. Since risk assessment is an iterative process, conceptual models can be modified and improved as knowledge increases. Conceptual models provide a framework for prediction and are the template for generating more hypotheses about risk.

4.5.3. Risk Hypothesis

A simple risk hypothesis can be formed by considering the conceptual model. For example: "Activities associated with the drilling and production of oil will cause negative effects on water quality, waterfowl, and the fish community."

4.5.4. Analysis

The analysis phase involves evaluating exposure to stressors and the relationship between stressor levels and ecological effects. When the exact receptors are determined and the stressors are more fully characterized, an analysis plan that is appropriate to the level of detail needed by the risk managers can be formulated. Toxicity values in the literature for different types of oil and sediments can be applied to the specific fish and wildlife receptors found in the Ob River. The Watershed Modeling System, developed by the EPA and the U.S. Army Corps of Engineers, may be used to determine the flow of water through the oil development area and the extent of

Figure 6

water movement in the floodplain. This would assist in analyzing the impacts of floods on moving sediments and the movement of oil in the stream channels.

4.5.5. Risk Characterization

In the risk characterization phase, risk is estimated through the integration of exposure and stressor-response profiles by discussing lines of evidence and determining ecological adversity for the particular situation in the Ob River. Additional, more specific information on the fish and wildlife receptors, the movement of oil and sediments in the flood plain, and the characteristics of the oil will be required. In the final phase a report is prepared for the risk managers and the public.

4.6 MAIN RESULTS

4.6.1 GIS

A composite map of the hydrology, vegetation, and infrastructure GIS layers is shown in Figure 7. All of the layers cannot be shown on one map and therefore a complete list of GIS layers is given in Table 2 in Appendix B. The natural conditions and infrastructure layers of the 1:25,000 GIS of Site 1 are shown in Figure 8. The 1:25,000 GIS has much more detail of the oil infrastructure than the Overview GIS including individual wells and buildings. A table of Site 1 coverages and more detailed discussion of the layers is given in Appendix B.

The EWG Oil and Gas subgroup decided that Site 3 was more important than Site 2 from a risk viewpoint because Site 3 will be developed in the near future whereas Site 2 will not be developed for some time. Therefore, the production of the GIS for Site 2 was postponed and the GIS for Site 3 was completed. The 1:25,000 GIS for the Site 3 GIS is shown in Figure 9. Since Site 3 is undeveloped at present the oil infrastructure layers are less detailed than for Site 1. Otherwise, Site 3 has many of the same layers as the Site 1 GIS. A table of Site 3 coverages and a more detailed description of the layers is given in Appendix C.

Figure 7

Figure 8

Figure 9

4.6.2 Ecological Risk Assessment Algorithms

Oil Spray

The main characteristics of oil composition that determine its impact on soils and wildlife depend on the presence of the following: 1) light particles, 2) cyclic hydrocarbons, 3) paraffin wax, 4) tars and asphaltenes, and 5) sulfur. Methane hydrocarbons (alkanes) constitute the main component of light particles. Normal non-branched alkanes account for 50-70% of this fraction. Methane hydrocarbons are strong narcotics that cause severe toxic effects on living organisms. Aromatic hydrocarbons constitute from 5% up to 55% of the total oil volume, more frequently 20-40%. Aromatic hydrocarbons represent the most toxic component of oil. It is known that oil's herbicide activity grows as its aromatic content increases. Benzene and its homologues provide a faster impact on organisms compared to saturated aromatic hydrocarbons. Sulfur compounds also cause a relatively strong impact on living organisms. Hydrogen sulfide and mercaptans have the most toxic effect. Hydrogen sulfide is present in a soluble form in oil or water and in casing-head gases. It is formed as a result of sulfur oil pollution of water reservoirs and soils with excessive drainage (gley, swamp, and meadow soils). Hydrogen sulfide is a strong toxin that causes great harm to animals and humans if its air concentration levels are high (1 mg/l). In addition, hydrogen sulfide is harmful to vegetation. The maximum acceptable air concentration level for hydrogen sulfide is 3 mg/m^3.

As discussed earlier, during oil spills a significant portion of oil products transform into gases as they evaporate and volatilize. The area of dissemination of volatile particles would depend on the air temperature, population density, speed and direction of winds. A simple model of the dissemination is given in the next section. Pump stations and central oil collection units serve as a source for permanent discharge of volatile hydrocarbon particles into the environment. At such sites of pressure increase and pumping into pipelines oil is split into liquid and gas fractions. Experience shows that significant volumes of oil products in the form of volatile particles are constantly discharged into the atmosphere from those sites due to leaks. According to experts, volatile hydrocarbon particles are the most toxic compounds in oil and, therefore, recurrent discharge of such particles into the atmosphere causes serious environmental stress.

As a first step toward calculating the risk of this process, a simple physical model is presented. An important step in designing the model is identifying the physical variables that determine the transport of the spray droplets. This model does not describe the production of the droplets which is a very complex process that depends on the pressure, leak size, internal temperature, and external temperature. Often, the most effective way to deal with the complex production process is to measure the spray *'in situ'*. But for the purposes of risk prediction where the spray source does not actually exist the uncertainty in droplet size distribution is a large component of the risk uncertainty.

For transport calculation, the important external variables of the oil spray are its height and production rate. The important internal details of the spray are the droplet's size and density. Atmospheric variables of importance include the wind speed, wind direction, and wind variance. Each of these variables is known with some degree of uncertainty because of natural variability (wind speed and direction) or lack of knowledge (droplet size distribution). Because of the uncertainty in the parameters, a very detailed physical model does not necessarily increase the accuracy of the risk analysis. In contrast, a simple model gives scaling laws that show the sensitivity of the risk to the physical variables and their uncertainties, which show whether greater measurement precision is required before invoking engineering risk-avoidance measures.

An individual droplet approach is taken here (further refinements to the model would include a multidimensional solution to the diffusion equation including turbulence). The droplets are produced from a leak in an oil transport structure (pipeline, derrick, or pump station). After an initial vertical drift due to leak orientation and entrapment by buoyant heated air, the droplets are convected horizontally at the wind speed and then drift downward because of their weight. Because of viscous drag of the atmosphere, the droplets rapidly come to a terminal drift velocity given by:

$$V = (2\ g\ a^2\ n)/(\ 9\ \mu)$$

where a is the droplet radius, n is its density, μ is the viscosity of air, and g is the gravitational constant. This relation is valid when the Reynold's number of the falling droplets is less than one. The droplets on average reach the ground in a time, $t=h/V$, after reaching their initial height, h, which includes their initial vertical drift. The horizontal range of the droplet is $r=U\ t$ where U is the wind velocity. Averaging over a long time, the wind direction is, to lowest order, uniform in direction (with a slight bias that is seasonally dependent) and uniform in magnitude between 0 and 2U. For a uniform oil loss rate, q (gm/sec), the dose, d, is:

$$d = (q/\pi)\ (V/Uh)^2.$$

The dose extends over an area A ($=\pi\ r^2$). This dose will continue to build up on the exposed plant surfaces until rain or some other agent washes off the oil residue. This simple model was programmed using the GIS database of the Priobskoye oil field so that the plume from any possible spray source and the resulting "footprint" can be compared with the location of economically important vegetation or water resources.

The dose described above assumes that the oil droplet does not change during flight. In fact, the volatile components evaporate. Evaporation is dependent on molecular weight and droplet diameter. For Benzene droplet diameters of 1, 10, and 100 microns the time for evaporation was 0.22, 2.2, and 22 seconds for a wind speed of 10 m/s and air temperature equal to 15° C. This relationship shows that the region of volatile ground contamination is determined by the large droplets which have the short flight time (and dispersion range) and land before the volatile components evaporate. Smaller droplets drift further but have no volatile components when they land. Since the light components are most lethal, there are two zones of droplet contamination— an inner zone of plant destruction and an outer zone of oil coating and growth reduction.

The effect of uncertainty on the calculation of risk involves contributions to uncertainty from the probability of an oil spray occurrence, the fate of the spray, and the effects of the oil spray on receptors such as valued tree species. In the following analysis a method of including the effects of uncertainty on the fate of the spray is given. The simple oil spray model gives the deterministic flight trajectory for the given initial conditions. Not all drops will land in the same place because their initial conditions vary. There is variation of the wind speed and direction (on many time scales) as well as the variation in droplet size and effective height.

Let us look at the inaccuracy of modeling for oil spray effects using the mean value for the parameters. The oil spray concentration, D, accounting for uncertainty in q, V, U and h is:

$$D = \int \int \int \int d(q,V,U,h)\, p(q,V,U,h)\; dq\, dV\, dU\, dh$$

where D is the dose with uncertainty factored in and the function, p, is the probability of the variables having a particular value. Notice that the dose function, $d = (q/\pi)\,(V/Uh)^2$, is separable into the product of powers of its dependent factors. We will assume that the probability p(q,V,U,h) is separable as well. Then the integral above can be separated into the product of four integrals.

$$D = \int q\, p(q)\, dq \;\int V^2 p(V)\, dV \int U^{-2}\, p(U)\, dU \int h^{-2}\, p(h)\, dh$$

These integrals are the moments of the probability distributions and the formula for D can be simplified to:

$$D = \langle q\rangle \langle V^2\rangle \langle U^{-2}\rangle \langle h^{-2}\rangle$$

by using the convention,

$$\langle a^n\rangle = \int a^n\; p(a)\, da$$

For the case where n=1 the first moment, $\langle a\rangle$, is the mean. When the n=2, as is the case for the droplet speed, then the 2nd moment is not in general equal to the mean squared. That is, $\langle a^2\rangle \neq \langle a\rangle^2$. This result shows that using mean values for probabilistic (uncertain) variables in physical models can lead to errors. If a single value for velocity (or other parameter) is used in the model it should be corrected for this type of bias. This bias problem can be avoided if multiple simulation runs are performed using a probabilistic distribution of parameter values --the so-called Monte Carlo method. However, for ‘n’ uncertain parameters this n-dimensional matrix of computer runs can be time-consuming.

Road Construction Algorithm

The following algorithm was used for road construction:

Analysis of general information on the research area (soils, landscape features, surface waters, hydrogeology, ground rocks, meteorological conditions, biota, and technogenic factors).

1. Formulation of a hypothesis on predominant factors of anthropogenic impact.
2. Processing of images and depicting pseudo-similar contours for predominant anthropogenic factors.
3. Planning for collection of additional (refined) information, including in situ data on soils, landscape features, surface waters, ground rocks, hydrogeological regime, climate, biota, anthropogenic impacts, and pollutants within several comparable contours.
4. Development of a Geoinformation system (GIS).
5. Qualitative and quantitative analysis of additional information and characterization of previously delineated comparable contours.
6. Additional processing of images to define results.
7. Determination of qualitative levels of resilience against anthropogenic impact for each contour.

Formulation of the hypothesis on predominant factors of anthropogenic impact considered such major impact categories as infringement of natural drainage, pollution with petroleum products, ponding-drainage, and pollution with construction and municipal waste. Other impact categories (e.g. improved access to undeveloped territories) were considered insignificant compared to the aforementioned factors.

Zoning of the territory was conducted along with delineation of sites with pseudo-similar landscape-geochemical and hydrogeological features. Qualitative resilience levels were determined for each site-contour. Rare and economically valuable fish, waterfowl, and forests were identified as receptors affected by impacts. After the territory was divided in contours with similar resilience, road construction simulation was conducted in the most sensitive area - the flood plain.

In addition, an assumption was made, based on economic benefit, that such a road in the flood plain could be constructed, especially for achieving an increase in summer accessibility.

Therefore, the location was selected to connect both river banks and at the same time connect the settlement and oil storage facilities with oil well clusters. Other objectives were not included in the task description. Thus, this road exists only in the experts' imagination, but it provides an opportunity to clearly depict the aspects of ecological risk that are associated with the planning and decision-making process.

The experts developed two hypothetical options for road construction: an almost straight line and a meandering line with a western trend. In addition, the end condition for the first option was determined not to include drainage and to use artificial mounds for road construction. The end condition for the second option used pile-up construction materials and intensive horizontal drainage. The input data were based on a map of environmental stability assuming that according to cost and ecological risk indicators the first option will be the cheapest (cheap if there is no drainage and expensive if a system of intensive drainage is put in place) and create the largest hazard to the environment, whereas the second option will be more expensive, although environmentally less dangerous. Experts agree that both construction options will create hazards because the road will cross over the flood plain.

Later, a model was developed to include directions of water movement and water consumption during various seasons, as well as of well cluster location (considering possible oil spills), fish migration and spawning features, specific features for waterfowl feeding grounds, oxygen content in different seasons, soil conditions, environmental stability, relation of the road to water streams (surface and ground), construction process, and road building (alluvium, embankment). It was stipulated that the remaining features were insignificant and required additional research activities.

The two proposed options, accompanied by an ecological risk map, were incorporated into the GIS. (A summary of conclusions and comments is described below in section 4.6.3.2, Road Construction Stressor)

Oil Spills

To properly conduct a risk assessment, the probability of the occurrence of a spill (and the associated spill rate and duration) is needed. This probability distribution is dependent on many factors, some of which are conditionally dependent on others. Also, the probability distribution is not determined only by natural effects such as the wind speed. Rather, it depends on many engineering and construction decisions such as:

1) Construction design (pipeline quality, elevated or buried).
2) Adherence to design specifications during construction
3) Maintenance after pipeline construction

Given the engineering practices, many potential factors could affect the probability of a spill. For instance, curved pipe sections or joints are known to fail more often than straight ones. Frost heave for buried pipes and flood or ice scouring are spatially varying physical causes of failure. Permafrost can be a factor in subarctic regions, but the Priobskoye oil field is free of permafrost.

Spill frequency of existing pipelines in Russia is an indicator of expected failure rates for new pipelines if the same engineering practices are followed. A widely reported spill from the Komi region occurred in 1995. Actually, the Komi pipeline spill was not one, but many spills from a 17 year old pipeline. The cause of the failures was corrosion from within the pipe, especially due to the presence of produced water which was not extracted at the well head.

In addition to the occurrence of a spill, the other quantities which must be known are the spill rate and the spill duration. As discussed in the Amoco EIS, the scenario of a small undetected spill may result in more total oil loss than a larger but soon-detected spill. However, without a relative probability of each type of spill occurrence the risks of the two cases cannot be compared quantitatively.

When a spill does occur, it has a strong negative impact on environmental conditions. Several factors have an impact on oil spills and the consequences of such oil spills. Some of the factors are related to oil composition, whereas other factors reflect natural conditions at the time of oil spills. Depending on the oil's grade and characteristics, an oil spill could cause dramatic consequences on the environment. Oil consisting of light hydrocarbons with a short molecular chain evaporate readily and volatilize quickly, although such oil grades are the most toxic. Heavy hydrocarbons with long molecular chains don't have a tendency to disseminate quickly and usually settle on soils and water surface becoming stagnant for a long period of time, thus hampering mitigation efforts. According to our data, oil in the Priobskoye oil field is relatively heavy with a density of 29 to 30 degrees by the American Oil Institute standards.

Oil impact is split into two types: a zone of direct impact of the oil spill and a zone of oil spill effect. A zone of direct impact caused by an oil spill is an area where oil is in direct contact with the ground or water resulting in an oil coating on it. Such areas are characterized by an extremely high content of oil products. An area of oil spill effect is an area that is characterized by an increased content of oil products caused by the spread of oil products into adjacent areas by way of water-oil emulsions and oil coating through and on the surface and ground waters as well as by volatile hydrocarbon particles.

Environmental conditions (including seasonal effects) in a particular area also provide significant impact on the dissemination of oil pollutants. Important parameters required for an assessment of oil spill dissemination include: landscape, vegetation, pipeline construction routes, direction and speed of rivers and streams, wind direction, and temperature. In addition, processes such as evaporation, dispersion, and emulsification are important for calculating the time that oil would remain in the environment. Evaporation is the most critical factor in calculating the time and area of oil spill dissemination. Evaporation depends on the area of oil spill dissemination as well as the temperature at the time of an oil spill. Obviously, during the summer the volume of evaporated oil would be greater than in the winter. Based on expert opinion of our scientists, it's assumed that 25% of the oil would evaporate within 24 hours for an oil spill during the summer season. In the winter season, the volume will be smaller and evaporation would account for approximately 15-20% of the oil. Dispersion and emulsification factors will be applied to calculating the area of direct impact and oil spill effects. However, our data suggests that these factors are insignificant.

The prediction of oil spill evolution is very complicated. In addition to expert opinion, modelling is a useful approach. A discusssion of a modelling approach follows. First, we break the spill environment into two types: water and land. In the Priobskoye flood plain, an oil spill has about an equal chance of occurring in or near a water body as on dry land (when averaged over all seasons). First, we will discuss the case when the oil spills directly into water. Although it is clear that spilled oil will spread over the water body, the concentration cannot be determined without a physical model of the transport. Models for oil spills in water are better developed than for land spills because spills in water from tankers or offshore platforms are the most common scenario and the physics of spills on water is simpler. One of the simpler models is based on turbulent diffusion. The model gives oil concentration when source and environmental parameters are known. Modifications to include evaporation and other loss mechanisms are possible but not included in what follows. The model for the concentration, N, of a oil contamination water-borne plume with a continuous source is:

$$N = [q / 2\pi U\sigma^2] \quad \exp(-y^2/2\sigma^2): \quad \sigma = \sqrt{(2D)}\, x/U$$

where U is the drift (due to current and wind along x), D is the diffusivity, and q is the source strength. This expression is good far from the source. The correct form for all distances, r, from the source is:

$$N= [q/(4\pi Dr)] \exp\{-[U/(2D)](r-x)\}$$

where $r=\sqrt{(x^2 + y^2)}$. Although it appears that there are three independent variables, in fact there are four because the above formula assumes that the wind is blowing along the x-axis. For an arbitrary wind direction (θ) with respect to the x-axis, N is obtained using the coordinate transformation

$$x=x'\cos(\theta)-y'\sin(\theta); \quad y=x'\sin(\theta)+y'\cos(\theta).$$

For instance, if the wind is from the northwest (toward the southeast), then $\theta = \pi/4$. If all the parameters are known for a given spill, then the plume model can be evaluated as a prediction. But for a risk assessment the expected distribution of values of D, θ, q, and U should be used to account for the uncertainty in the spill size and the intrinsic variability of nature. The mathematical method to account for uncertainty is to average over the probability distributions of the parameters. Then the "expected" oil concentration is:

$$\langle N\rangle = \int \{ \int [\int \{ \int N(U,q,\theta,D)\, p(U)\, p'(q)\, p''(\theta)\, p'''(D)\, dU\}\, dq]\, d\theta\}\ dD / P$$

where the normalization factor, P, is:

$$P = \int \{ \int [\int\{\int p(U)\, p'(q)\, p''(\theta)\, p'''(D)\, dU\}\, dq]\, d?\ \}\ dD$$

Although this method is better than just using the average wind speed and direction, it is an incomplete description of uncertainty, because there is uncertainty in the probability distribution itself (i.e. Gaussian, Gamma, or other). Even so, this model shows the sensitivity of the risk to various parameters. If the parameters can either be measured more precisely or controlled (e.g. by pipeline placement), then the risk will be much more accurately defined or even lowered.

Some of the parameters are dependent on the season (wind speed and direction, for instance). This model is not applicable for ice-covered rivers and lakes because the assumption is that the oil is drifting due to wind or current in and on liquid water.

For spills over land, the fate and transport model is greatly complicated by topography, vegetation, and ground absorption, as well as evaporation. Topography is especially relevant because it gives the direction of oil flow in the event of a spill. This, in turn, gives the positions of entry into nearby water bodies and can predict the risk of individual water bodies to a proposed pipeline configuration (given that the probability of a spill from each pipe segment is known). The speed of the oil spill flow will obviously be dependent on the temperatures of the oil and the atmosphere. Due to this complexity, the oil spill fate on land can only be analyzed approximately at this time. For instance, in the examples section the critical entry points for water bodies can be determined by the gradients in the topography and the pipeline location but the concentration of the spilled oil is unknown.

Finally, while the fate modeling can establish the exposure to oil products, the dose to an actual receptor requires the receptor to be present in the area. For the chosen receptors, there is a large seasonal variability in species occurrence in the study areas. This data has been obtained and is discussed in the examples section. The consequences of the exposure depend on the sensitivity of the receptor to the stressor and the chosen endpoint (tainting, disfigurement, or mortality).

41. Risk Assessment Examples - Site 1

The risk assessment examples were chosen following the guidelines of section 3. That is, economically-valued vegetation, wildlife, and especially food sources of the small indigenous population were prioritized in the selection of the examples. In addition, display of the GIS technology and NSS data was given priority. The chosen receptors and stressors are listed in Section 4.5.1. The organization of the examples is as follows: first a stressor is discussed (including its fate and transport) followed by its effect on the chosen receptors.

4.6.3.1. Oil Spill Stressor

Oil spills are perhaps the most "disasterlike" environmental problem associated with these sorts of oil production activities. Even with all the safeguards developed by the oil industry, so much pipe is laid and so much time involved, plus the dynamic climate and movement of water, the chance for a spill is non-zero. It is the purpose of the risk assessment to point out the areas of maximum risk, which can then be reduced by design changes or the siting cleanup equipment in close proximity to high risk areas.

In the first example, simulated oil spills are analyzed at three points of existing and proposed pipelines. Then, results of extending the point calculations to the entire proposed pipeline are presented. The three oil spill sites correspond to three types of landscape conditions that are present in the test site 1 of Priobskoye oil field, i.e., river, flood plain, and terrace. We have considered a hypothetical situation where a pipeline breaks presumably due to erosion, engineering processes (sagging, heaving), accidental mechanical breaks in airtightness of pipelines (off-road vehicle, grader, icebreaker), or increase in acceptable pressure levels in pipeline. The result is an uncontrolled oil spill with oil volume hypothetically reaching 500 tons (until the time of eliminating the source of an oil spill). Oil spill response, containment, and remediation time is not determined. Such a hypothetical oil spill corresponds to a significant accident that would be an emergency situation on the regional level. This hypothetical situation is assessed for three seasons: winter, spring (flooding), and summer (dry).

We have applied the existing data and expert opinions of our scientists to the process of oil spill simulation. The results are illustrated in Figure 10 and discussed below in greater detail.

Point 1 is located in the area directly adjacent to the Ob River at a section of the proposed pipeline adjacent to the water surface. Point 2 is located in n area of the flood plain with a section of the proposed pipeline. Point 3 is located in the terrace area where a section of existing pipeline is adjacent to a road and an estuary of one of Maliy Salym's tributaries.

Spring Flooding

Spring flooding is potentially the most dangerous season for an oil spill. As mentioned above, during spring flooding, a large section of the flood plain is flooded, rivers become active, and discharge of water intensifies. Air temperature is approximately 10°C. Even elevated areas will be saturated with water or moist, and covered with numerous small streams.

Our assessment shows that at Point 1, the spill that would occur during a pipeline break would directly reach the Ob River. Due to evaporation, we assume that 20% of the spill would evaporate and volatilize. The remaining oil would form a coating (according to our estimates, the depth of the coating would be 0.1 mm) that would spread downstream at the speed of the river's current. Mathematical calculations by our experts estimate the oil spill area to be 4 square kilometers. It appears that a portion of oil would form a water-oil emulsion which would pollute

Figure 10

the riparian area. In addition, a part of the spill would be dispersed by inland waterways throughout adjacent territories, thus causing contamination of such areas. Point 2 is located in the flood plain area that resembles a lake rather than dry land during the spring flooding season. The spilled oil would partially evaporate (approximately 20%), partially transform into a water-oil emulsion, and be partially retained by non-flooded elevated areas that would serve as barriers to further spreading. The remaining oil would create a coating on the water's surface and its transport routes would follow the wind direction and water current. At Point 3, the spill would be dispersed along the landscape features and pipeline construction routes, although its spread would be limited by the adjacent road and pipeline. A portion of the oil would likely reach the Maliy Salym river via its tributaries. Thus the spill would be spread downstream at a speed of the river's current. The spill would reach adjacent territories through Maliy Salym's tributaries.

Impact assessments should also consider such factors as sedimentation of the oil's heavy constituents on the bottom of rivers and streams and contamination of riverbeds, and the resulting decrease in oxygen concentration in the water and reduction of the fish feeding grounds due to oil coating of microflora and fauna.

In addition to the three point analysis of risk described above, a relative risk analysis based on the concentration of oil from each possible spill location on a proposed pipeline was undertaken. The model used was the turbulent diffusive plume described in the previous section. To speed the numeric processing of this multi-point problem, the method of convolution was used. A kernel function was constructed using the algorithm discussed in the algorithms section (including the uncertainty and variability of natural conditions such as wind speed and direction). The kernel was convolved over all of the pipeline which would be flooded during the spring. The GIS flood layer was used to mask out the pipeline segments which will be inundated in the spring. As shown in Figure 11, the oil concentration is highest in the water just adjacent to the pipeline spill. The results also show that some areas have higher risk because they are at overlapping points of spill plumes from many points on the pipeline.

The modeling of spills reaching wetlands from spills on dry ground is much more difficult because the oil absorption into the ground and oil flow over terrain must be taken into account. As a first step, the path taken by spill was calculated using a digital elevation model created from analysis of flood levels in civilian and NSS data. This elevation data is relative, but it does determine the direction that the spilled oil flows (down the steepest terrain gradient and along the pipeline route). The location of spill entry points to water bodies is also shown.

Figure 11

Summer Period

Oil spill characteristics in the summer period would be somewhat in-between the two aforementioned scenarios, with the exception that in the summer, the evaporation factor would be more significant and would account for approximately 25% of the spill. Moreover, the presence of vegetation that retains oil would serve as an additional limiting factor.

The spill at Point 1 would reach the Ob's main riverbed and spread downstream at the speed of the river's current. At Point 2, an oil spill would spread along the route of pipeline construction and landscape features. Elevated areas would serve as natural barriers to its flow along with vegetation that would also retain some oil. However, if the spill reached waterways, it would spread over the water's surface and be dispersed throughout remote areas. At Point 3, the spill would spread along pipeline construction routes and landscape features. Elevated areas would serve as natural barriers along with vegetation that would retain some oil. Other natural barriers would include adjacent roads and pipeline construction areas. However, it is quite possible that the spill would penetrate into a tributary of the Maliy Salym, through which it would easily reach the Maliy Salym river and spread downstream at the speed of the river's current, thus polluting the riparian areas.

During this relatively dry season the rivers and other waterways are relatively shallow. Therefore, the predominant spreading of the oil along smaller tributaries and streams would be considered as risk factors.

Winter Period

We believe that oil spills would have less impact on the environment during the winter season, with the possible exception of Point 1 where the spilled oil would penetrate under the ice and drift downstream at the speed of the river's current. In this case, oil would be located between the water surface and the ice, and it could spread downstream throughout large areas. This scenario would create significant difficulties for removing the oil from under the ice cover, while oil evaporation would be insignificant due to the limited area of the oil's contact with the atmosphere as well as the low temperatures. Therefore, we can assume that the total volume of the spill would penetrate under the ice and spread downstream throughout large areas, unless localization and water surface clean-up activities are implemented in a timely manner. Such factors as dispersion and emulsification of oil in water would also play a significant role by causing a negative impact on the ecosystem components of the Ob River and its riparian area. An oil spill would not provide such a strong impact at Point 2 in the flood plain as at Point 1 next to the river. This scenario assumes that the spill would reach the ground and slowly spread in the direction of pipeline construction and along landscape features, i.e., the riverbed of a stream or a river that is located directly adjacent to the oil spill area. In this situation, limiting factors would include the low atmospheric temperature that would cause oil condensation and decrease its spreading speed, as well as the presence of snow cover. Evaporation would play a major role in this scenario by causing probably 15% of the spilled oil to evaporate and volatilize. We believe that Point 3 would be characterized by a situation similar to that at Point 2, although it would have additional limiting factors due to an adjacent road and pipeline construction area where some oil would be retained.

In order to analyze the risk for a proposed pipeline, the critical entry points to water bodies for all points on the pipeline were analyzed using a digital elevation model to determine to oil spill flow direction. The digital elevation model was constructed from flood contours (low, medium, and high), visual inspection of image data, and maps. The elevation data was further constrained to be consistent with river and stream drainage. The digital elevation data is shown in Figure 12 and the results of the oil flow direction analysis are shown in Figure 13. The points of entry into water bodies are shown in yellow. As discussed above, the additional data needed to precisely model the oil spill fate and transport are the evaporation rate, oil viscosity, snow depth, and ice thickness for the larger streams which are not completely frozen. All of these data are very uncertain for the frigid winter conditions.

Oil Spill Effects on Selected Receptors—Fish, Waterfowl, and Forest Vegetation

Fish

For rare and economically valuable fish, contamination with hydrocarbons that are present in water-oil emulsion would have a lethal effect on the majority of fish and would cause a decrease in fish quality and, subsequently, a decline in prices on marketable fish (a more important factor for economically valuable fish). The risk map is the convolution of the oil spill fate map (Figure 10) with the resiliency map (which is mainly determined by occupancy). The details of the fish resiliency are given in Appendix B. Briefly, the effects of an oil spill on the fish are most pronounced where their concentration is greatest, and during the sensitive spawning stages. Many of the fish are migratory, but some breed in the area. The spawning is most productive in the shallow lakes, called sors, which are inundated by the flood and dry out as the season progresses. A pipeline break at this location during the spawning season is very serious. The pipeline route was designed to stay away from as many sors as possible. But the route by which the oil could reach the spawn is highly variable. If the spill is not into the sor, then the

Figure 12

Figure 13

exposure path could be either overland or via connected water. During the winter, fish congregate in oxygen rich waters in tributaries of the Ob. The pipeline segments upstream from The risk to fish presented in Figure 14 is relative until probable spill volumes are determined from historical pipeline data (with risk reductions for improved pipes, maintainence, etc). At that point, the economic risk of pipeline spills is calcuable.

Waterfowl

Due to natural behavior and life cycles, waterfowl species are extremely vulnerable to oil spills. Three categories of waterfowl's vulnerability are:

1. Physical impact of oil on thermoregulation and flotation capabilities of birds.
2. Smearing with oil (loss of ability to fly, disturbance of heat exchange and access of oxygen).
3. Toxicity of hydrocarbons consumed during cleaning of feathers and ingesting contaminated food.

As a rule, all three groups have simultaneous impact, although even one group can have lethal effects. There are several ways that birds can be trapped in an oil spill: by an oil spill that spreads to waterfowl's habitat, or by an oil coating that floats downstream (due to an oil spill), or by attraction of birds to the oil's shine on the surface which gives the appearance of a calm lake.

The ecological risk assessment for three oil spill locations (henceforth referred to as points 1, 2, and 3) was conducted for two seasons - spring flooding and summer (Figure 15). Expert research for the purpose of ecological risk assessment was conducted based on the maps of environmental resilience and population density.

The oil spill area itself is always a high risk zone, excluding a situation when the oil penetrates into the areas with high environmental resilience. For example, at point 1 of the oil spill, the fraction of the oil that penetrates into the river would be quickly carried away by the current and diluted in large volumes of water. In addition, according to the existing data, waterfowl species prefer flood plain lakes and marshes over a large open area of the river (plus, commercial navigation and mitigation activities would disperse the waterfowl). That results in a low ecological risk for waterfowl relative to the risk factors. As for point 2, oil coating and the spill's intersection with waterfowl's preferred habitat are the most important factors.

Figure 14

Figure 15

Vegetation

Dissemination of oil on the ground creates two zones characterized by different levels of contamination of substratum and degradation of vegetation communities. The first zone is an area of direct oil coating of the surface with complete destruction of vegetation. The second zone is a transitional area where: 1) oil is not present on the surface of the moss cover, 2) insignificant volumes of oil are present in the substratum, and 3) partial destruction of vegetation is observed. Transitional areas are created as a result of oil leakage under moss cover in the border area between organic and mineral soil horizons. Such areas could account for 5-30% of the entire polluted territory.

If an oil spill occurs during spring flooding, than its impact would be significantly less than during the winter or summer seasons. We believe that impact on forest stands during the winter would be significantly less than in the summer since deep layers of soil freeze and oil would not be able to penetrate deep into the soil, while in the spring a portion of the oil would be washed away by flood waters. In addition, the lightest and most toxic oil components would evaporate during the winter season. The spilled oil would be retained at shallow depths in watersheds that could not be reached by water during floods due to high levels of ground water during the spring season.

If the contamination level is low (up to 10%), new growth of coniferous and deciduous tree species would be observed one year after the spill and the volume of viable recovery of forests would reach its normal level in 5 to 6 years. If the contamination level is medium, recovery processes would prevail over degradation processes in 4 to 5 years after the spill. By that time, extensive new growth of coniferous tree species would be observed. Extensive new growth of deciduous tree species (birch and aspen) would appear one or two years earlier. The volume of young growth would reach 87% of its normal quantity in ten years. If the contamination level is high, the first scattered new growth of deciduous tree species would be observed in 6 to 7 years. According to our data, there would be no new growth of coniferous tree stands even in 15 years after the spill.

4.6.3.2. Road Construction Stressor

.6.3.2. Road Construction—Method and Map Road construction poses a serious threat to the environment. As a rule, road planning is based on economic effectiveness and safety concerns. Road construction is the most important end condition for ecological assessments. As a rule, it comprises a number of factors, such as ponding and drainage of terrain on both sides of the road, which leads to infringement of the hydrological and hydrogeological regime of the territory. Another factor is contamination of the territory during road construction and operation with construction and general waste and oil products that contain toxic and hazardous materials. Another factor under consideration is the infringement of landscape integrity, which leads to an increase in erosion processes and subsequently, to problems of the engineering buildings' security that will cause additional ecological problems. There also is the problem of noise pollution. Finally, there is the problem

of new ecological risks that are related to construction of additional engineering facilities along the road, such as power lines, pipelines, etc. Other specific environmental problems can be observed in the research area, such as a decrease in the biochemical indicators of oxygen.

The aforementioned problems serve as baseline factors for ecological risk assessment. On the other hand, direct impact is applied to vegetation, soil, fish, waterfowl, other species of wildlife and finally (rather, first and foremost), to people. Such effects are first visible in the change of natural conditions. Migration capabilities of fish are violated, which leads to disruption of spawning and feeding grounds. Disruption of oxygen content, which is naturally low in bogged water with a high content of organic elements, causes higher fish mortality. Ponding and drainage of the territory due to a "time dam" effect causes a change in vegetation and soil composition and subsequently, change in microflora. Effects of pollutants on the wildlife and other aforementioned factors should be noted, although this report does not provide a detailed description of impact mechanisms, but rather a description of general directions and characteristics of the ecological risk assessment.

The road construction example is a purely hypothetical assumption that portrays the above- mentioned environmental problems. Although road construction is not planned in this area, such an example provides initial information on the problems that might be avoided, or at least assist in minimizing environmental impact.

In keeping with the choice of receptors to be examined, the effects of road construction on waterfowl are discussed next. Although its direct impact on waterfowl's habitat is relatively small, road construction would lead to an increased disturbance of waterfowl. The disturbance factors are as follows:

1. Dispersal of waterfowl during road construction and maintenance (direct impact).
2. Improved access to waterfowl's habitat.
3. Pollution with municipal waste and increase in water toxicity.

Noise that exists in the area of road construction has a significant impact on waterfowl. In addition to noise, the dispersal factor (item 1) also includes visual disturbance. Since it is very difficult to distinguish between noise pollution and visual disturbance in regard to waterfowl, we will consider both effects in the dispersal factor as one. Road construction will lead to an improved access to previously inaccessible areas of waterfowl's habitat. This factor could aid the hunters in reaching and disturbing the waterfowl's habitat where it has not happened in the past. An improved access to waterfowl's habitat in the summer and its nesting grounds can be classified as one of the most harmful effects of the area's development on birds that inhabit the research area of Priobskoye oil field. In addition to increasing the number of people in the area, an added factor is predation against waterfowl. For example, waterfowl's eggs and offspring are extremely exposed to such predators as seagull, skua and fox especially when the presence of people in the area makes mature birds leave their nesting grounds. In addition, people's presence in waterfowl's nesting areas during the incubation period, feathering, and early stages of raising offspring could indirectly lead to the loss of many eggs and young species (fragmentation of flocks).

The road in Site 1 crosses the Ob flood plain and Maliy Salym river and runs through the terrace. The road is 50 meters wide which includes road lanes, cushioning layer, drainage ditches and adjacent territory covered with waste. In addition, we reviewed affected areas on both sides of the road that are 1 kilometer wide on each side. The majority of birds can be easily dispersed, and the noise pollution covers large open areas in the flood plain. Forests and tall vegetation serve as noise absorbers, although the road at site 1 crosses through sections of tall vegetation only after crossing over the Maliy Salym river where the developed territory begins. As mentioned earlier, the developed territory is under significant anthropogenic impact, therefore waterfowl do not inhibit such areas. As a result, ecological risk for waterfowl on the left bank of Maliy Salym is low. The risk increases in the areas where the road crosses sections of the waterfowl's preferred habitat.

As described in the bottom half of Figure 16, the aforementioned problems, as well as ecological risk, will be reduced if the road construction route is modified by introducing additional horizontal drainage systems and diverted to cross over high ground that is less sustainable to drainage effects. Moreover, the latter option provides an opportunity to preserve hydrogeological regimes and shallow lakes that serve as fish spawning grounds and feeding grounds for waterfowl.

This example shows adverse effects of road construction, under any conditions, on control of ponding effects that lead to erosion, settling, and other problems described above. On the other hand, it provides an opportunity to initially minimize ecological consequences. The baseline for any road construction, in view of ecological risk, should be assessment and control

Figure 16

of environmental resistance against certain exposures and maximum preservation of environmental potential to withstand such an impact.

4.6.3.3. Oil Spray Stressor

Oil contamination of the air can occur during the drilling and production process. During drilling a "blowout" of a highly pressurized field can lead to large releases of oil into the air and terrain. The Priobskoye field is under low pressure, so the risk of blowout is small. After production begins, the pumping stations and other equipment can produce small leaks that produce aerosols. The pathway of the aerosol is largely dependent on the wind. The characteristics of the aerosols depend on the oil type, water content, aperture size, pressure, and ambient temperature. In the frigid conditions typical for half the year, freezing of the water and/or oil is a complex problem that may require empirical studies. During the summer, conditions are more amenable to modeling. The contamination is at nearly ground level but the spray may have an upward component. In addition, there may be updrafts, which give another vertical component. Thus the oil droplets become projectiles influenced by horizontal wind and air drag and gravity to produce a trajectory described in the algorithm section. The model spray trajectory described in the algorithm section (4.6.2) is a good illustration of the effects of uncertainty. With a large uncertainty in the oil spray parameters, the extent of the oil spray plume and its resultant damage could potentially include a very large area. Careful measurement of spray parameters would likely limit their range of deposition and lower the risk to forest areas. For the oil spray result shown in the Figure 17, the range of wind speeds and directions was taken from the Surgut meteorological station as reported in the Amoco EIS (1995). The droplet size distribution was modeled with a gamma distribution with a 50 micron mean for purposes of illustration. Similarly, the height distribution was a gamma distribution with a mean of 100 meters.

In conclusion, the research on the impact of light hydrocarbons on photosynthesis and viability of trees is not comprehensive. It seems that airborne impact of light hydrocarbons is considerably less than its impact through soils. Moreover, if light hydrocarbons do not cover the ground and are brought into the area by wind, then, most likely, the concentration of such hydrocarbons is relatively low and could cause harmful effect only on edge tree stands.

Based on the aforementioned factors, it can be noted that, in general, forests experience significant disturbance caused by volatile hydrocarbon particle under the conditions of chronic impact. It's likely that high ecological risk would characterize vegetation in the area adjacent to

Figure 17

such sources of constant pollution as pump stations and central oil collection units. Wind direction and speed should also be considered in calculating the area of pollutant dissemination.

Another atmospheric risk to the environment is oil burn-off. The impact is caused by oxygen depletion, thermal emission, and contamination of air, vegetation, and soils with products of incomplete burn-off of hydrocarbons, carbon monoxide, nitrogen oxide, sulfur dioxide, and other chemical compounds. The radius of direct thermal destruction ranges from 10 to 25 meters for soils and 50-150 meters for vegetation. In violation of oil development regulations, liquid components of oil will periodically penetrate into the oil burn-off units and pollute adjacent territories since such components will not burn up completely.

41 Risk Assessment Examples—Site 3

4.6.4.1 Oil Spill Stressor

This section describes the accidents that are have some likelihood of happening during future development of the Priobskoye oil field (test site 3). We have based oil spill simulations on the following stipulations. Simulated oil spills occur at three points along the proposed pipelines. Oil spill sites are located in the three main types of landscape features that are present in the Site 3 of Priobskoye oil field, i.e., river, flood plain, and terrace. We have considered a hypothetical situation where a pipeline breaks due to erosion, engineering geodynamic processes (sagging, heaving), accidental mechanical breaks in airtightness of pipelines (off-road vehicle, grader, icebreaker), or an increase in pressure levels in the pipeline, etc., thus causing an uncontrolled one-time oil spill with an oil volume of approximately 500 tons (until the source of the oil spill is stopped). Oil spill response and remediation time is not determined. Such a hypothetical oil spill corresponds to a serious accident that could be compared to an emergency situation on regional level. Such a hypothetical situation is assessed for three seasons: winter, spring (flooding), and summer (dry season). The results are summarized in Figure 18 and described in more detail below.

We have applied existing data and the expert opinion of our scientists to the process of oil spill simulation. Let's review each of the possible oil spill scenarios in greater detail. Point 1 is located in the area directly adjacent to the Ob River where a section of the proposed pipeline is adjacent to the Ob's water surface. Point 2 is located in the flood plain area (upper flood plain) where a section of the proposed pipeline will connect three oil well clusters that are presently under construction. Point 3 is located in the terrace at a turn in the proposed pipeline.

Figure 18

Winter Period

We believe that oil spills would provide the least impact on the environment during the winter season, possibly with the exception of Point 1 where spilled oil would penetrate under the ice and disperse downstream at the speed of the river's current. In this case, oil would be located between the water and ice and it could spread downstream throughout large areas. This scenario would create significant difficulties for removing the oil from under the ice cover, while oil evaporation would be insignificant due to a limited area of oil contact with the atmosphere (and the low air temperature). Therefore, we can assume that the total volume of the spill would penetrate under the ice and spread downstream throughout large areas, unless containment measures and water surface clean-up activities were implemented in a timely manner. Such factors as dispersion and emulsification of oil in water would also play a significant role by causing a negative impact on the ecosystem components of the Ob River and the riparian area. An oil spill would not provide so severe an impact at Point 2 (in the flood plain) as at Point 1. This scenario assumes that the spill would settle onto the ground surface and slowly spread in the direction of pipeline construction and along landscape features. In this situation, limiting factors would include the low atmospheric temperature that would cause oil condensation and decrease its spreading speed, as well as the presence of snow cover. The evaporation factor would play an important role in this scenario by causing approximately 15% of the spilled oil to evaporate and volatilize. We believe that Point 3 would be characterized by a situation similar to that at Point 2.

Spring Flooding

Spring flooding is the most "unfavorable" season for an oil spill could occur. As mentioned earlier, a large section of the flood plain is flooded, rivers become active, and surface water run-off intensifies during spring flooding. Air temperature will be approximately 10°C. Even in elevated areas the ground will be saturated with water and covered with numerous small streams.

Our assessment shows that at Point 1 the spill that would occur during a pipeline break would directly reach the Ob River. Due to evaporation, we assume that 20% of the spill would evaporate and volatilize. The remaining oil would form a coating on the surface (according to our estimates, the depth of such coating is assumed to be 0.1 mm) that would spread downstream at the speed of the river's current. Mathematical calculations by our experts estimate the oil spill area to be approximately 4 square kilometers. A portion of oil would form a water-oil emulsion and would be retained in the riparian area causing contamination. In addition, a part of the spill would be dispersed by other waterways throughout adjacent territories, thus causing contamination of such areas. Point 2 is located in the floodplain's rarely flooded area. It's assumed that this area would not be flooded and the spill would spread along landscape features and in the area of pipeline construction. The evaporation factor would be approximately 20% due to the low atmospheric temperature and the ground surface that would be covered by oil. Natural barriers to the spread of oil would be formed by elevated landscape features where the spill would be retained, thus polluting the soil. The presence of small streams and channels that are especially active during spring flooding would serve as an additional distribution path of petroleum products throughout large areas that are presently difficult to forecast. At Point 3, the spill would be dispersed along landscape features and pipeline construction routes, although its transport would be limited by forests and shrubs that are typical in this area. The evaporation factor as well as other factors would have similar effects as in the aforementioned scenarios.

In addition to the three point analysis of risk described above, a relative risk analysis based on the concentration of oil from each possible spill location on a proposed pipeline is shown in Figure 19. Impact assessments should also consider such factors as sedimentation of oil's heavy components on the bottom of rivers and streams and contamination of riverbeds. As a result, the oxygen concentration in the water would decrease and the size of fish feeding grounds would be reduced due to coating of microflora and fauna with petroleum products.

<u>Summer Period</u>

Oil spill characteristics in the summer period would be somewhat in between the two aforementioned scenarios with the exception that in the summer the evaporation factor would be more significant and account for approximately 25% of the spill. Moreover, the presence of vegetation that retains oil would serve as an additional limiting factor.

The spill at Point 1 would reach the Ob's main riverbed and likewise spread downstream at the speed of the river's current. It would be retained in the riparian areas causing pollution of the territory. At Point 2, the oil spill would spread along the pipeline route and landscape features. Elevated areas would serve as natural barriers on its way along and vegetation would retain oil products. At Point 3, the spill would spread along the pipeline routes and landscape features. Elevated areas would serve as natural barriers along with ground level vegetation, shrubs, and forests that would retain some oil. Note that during this relatively dry season the rivers and other waterways are relatively shallow. Therefore, the predominant dispersion of oil

Figure 19

coating would be directed along smaller channels and streams that would be considered as risk factors.

Fish

The risk to fish from an oil spill in Site 3 is summarized in Figure 20 by fish type and river region. Notice that the relative risk is based entirely on the relative occurrence of the species. This would change if there were statistics or a model which suggested that the probability of a spill was seasonally dependent. More details of the causes for the relative risk shown in Figure 20 are discussed below.

In the Ob River, the members of the sturgeon family (sturgeon, sterlet) are at risk because they are not present in the Ob due to low oxygen levels. Between Early April and June sturgeon are not yet present in the Ob River but sterlet are present and at medium risk. Between July and October the risk to sturgeon is high because spawning and migration of sturgeon begin with peak levels reached in September; also, reverse post-spawning migration downstream of the previous year's spawning sturgeon begins and migration of new sturgeon offspring begins. From November to early January there is increased risk because spawning migration of sturgeon is complete but flow migration of spawning species and offspring continues.

In the Ob River, the members of the Whitefish family (white salmon, muksun, peled, and whitefish) are at low risk from early January to early April because whitefish species are not present in the Ob River due to low oxygen levels. From early April until June these species are at medium risk due to migration of the previous year's spawning species and offspring. From July to October the risk is high because: 1)spawning migration of white salmon, muksun, peled, and whitefish species begins in the river with peak levels reached in September, and 2) reverse post-spawning migration downstream of the previous year's spawning whitefish species. From November to early January the spawning migration and flow migration of mature species and offspring is almost complete and so the risk is medium.

The economically valuable fish resident in the Ob at site 3 are: ide, dace, roach, pike, and perch. Due to low oxygen levels between early January and early April these fish are at low risk because they are not present. From early April until June, these fish are at medium risk due to their migration from wintering grounds to spawning grounds. From early April until June these fish are at medium risk as they migrate from their wintering grounds to their spawning grounds. Between June and mid-July the risk is medium because a limited number of these fish remain in the main riverbed. From July until October the risk is high since the mean water level decrease and the majority of fish migrate to the main riverbeds. Also, migration to wintering grounds

Figure 20

begins. From November until early January the risk is increased as the migration to winter grounds ends.

Besides the main channel of the Ob, other waterways in Site 3 are the Balinskaya river and the Labytvor channel. The members of the sturgeon family are not at risk because they are never present in these rivers. The peled member Whitefish family is the only one at medium risk between June and October when it may be present in the Balinskaya or Labytvor channel. Economically valuable fish (ide, dace, roach, pike, and perch) are at high risk if an oil spill occurs on the Balinskaya between early January and early April because numerous wintering sites are in Site 3. Even from early April to June the risk is high because this river is spawning and offspring development grounds for the majority of economically valuable fish. The risk is reduced (but not negligible) from June to mid-July as a significant fraction of mature fish and offspring migrate to feeding grounds in the flood plain. The relative ratio of fish per species (in percent) for dace, ide, roach, pike, and perch is 6.8/25.6/20.1/14.0/20.4. From July until October the risk is high again as the majority of fish migrate to tributaries. The risk in these rivers is high from November until early January as the wintering migration ends and the majority of fish assemble in the wintering grounds.

The risk in Shaytanka river and other adjacent rivers from an oil spill is low for the sturgeon and whitefish family which are absent throughout the year. For the economically valuable fish (ide, dace, roach, pike, and perch) between early January and early April it's impossible to calculate risk (if favorable wintering grounds exist, then the area should be classified as increased risk due to the fact that the number of such grounds would be less than in previous site; if there are no favorable wintering grounds then the risk is low). However, from early April to June the risk is high because this river is spawning and offspring development grounds for the majority of economically valuable fish. The risk is reduced (but not negligible) from June to mid-July as a significant fraction of mature fish and offspring migrate to feeding grounds in the flood plain. From July until October the risk is high again as the majority of fish migrate to tributaries. The risk in these rivers is high from November until early January as the wintering migration ends and the majority of fish assemble in the wintering grounds.

For the many flood plain lakes, channels, and sors the risk from an oil spill is low for the sturgeon and whitefish family which are absent throughout the year. Economically valuable fish (ide, dace, roach, pike, and perch) are at low risk from early January until early April because fish are absent due to unfavorable wintering grounds. From early April until June there is increased risk for these fish (main flood plain channels could serve as spawning and offspring development grounds for a part of economically valuable fish). From June until mid-July there is high risk due to the intensive feeding of majority of mature economically valuable fish and offspring). From July until October the risk is medium because a small quantity of offspring and mature fish could be retained in flood plain channels and sors). Finally, from November until early January the risk is low since all fish leave the flood plain.

4.6.4 Waterfowl

The risk to waterfowl in the event of an oil spill at three selected points in Site 3 is shown in Figure 21.

41 Road Construction Stressor

We have based our road construction simulation on a scenario wherein the road that is presently under construction would connect the dock located on the Ob's right bank with Selyairovo settlement (also located on the right bank). We have applied similar principles to our ecological risk assessment as described in the site 1 section (see Figure 22). Road construction in a specific location will have less effect compared to Site 1. The road in Site 3 crosses through the forest that serves as a noise absorber which makes it possible to restrict the area of road impact. In addition, the section crossed by the road is an area of high ecological resilience which also serves as a factor that decreases the overall road's impact on the environment. Potential ponding that will eventually develop should not be classified as a significant stressor for waterfowl due to the aforementioned reasons, while gradual disappearance of the screen (forest) would introduce changes in the impact only after several years.

41 Oil Spray Stressor

We believe that pump stations and central oil collection units would serve as the main sources of environmental pollution by volatile hydrocarbon particles in Site 3 of the Priobskoye oil field. According to our information, at least three pump stations and one central oil collection unit are planned for construction in the research area. Therefore, dissemination and subsequent impact provided by volatile hydrocarbon particles would largely depend on wind speed and direction, as well as vegetation density in this area. Risk assessments for the receptor in the test site area is discussed below.

Forests

As described earlier in Section 4.6.2, we believe that the main sources of pollution with volatile hydrocarbon particles would be represented by the sites of constant discharge of

Figure 21

Figure 22

pollutants into the atmosphere with the high content of volatile hydrocarbon particles that would be providing a constant impact on adjacent forests. Therefore, such sites as pump stations and central oil collection units would provide maximum negative impact on forests caused by volatile hydrocarbon particles. As mentioned above, according to our data the construction of at least three pump stations and one central oil collection unit is planned for this site. According to some estimates and expert opinions of our scientists, 20-25 hectares of forest could be destroyed by constant impact provided by volatile hydrocarbon particles around one pump station. The area of volatile hydrocarbon particles' impact on forests would primarily depend on the speed and direction of wind, as well as population density and resilience of forests towards such type of impact (see Figure 23).

4.6.5 Example of the Utility of NSS data

The use of data obtained through analysis of space-based images from unclassified sources and unclassified information products derived from national security systems data was of paramount importance to performing the tasks of this research. A large volume of data is required to perform a detailed study of the research area. Such data could have been obtained by various means, for example, in situ observations and analysis of previously collected information. However, it is well known that detailed in situ observations is a very time-consuming and expensive undertaking, because it consists of several phases: search for and analysis of previously obtained data, direct in situ measurements, processing of in situ data, laboratory analysis of samples, analysis of the results, additional in situ measurements, etc. Many such problems can be resolved through the use of data obtained as a result of analysis of unclassified space-based imagery and unclassified information product derived from national security systems data; for example, space-based images can be used in order to determine landscape features of the territory, vegetation types, river network, infrastructure, etc. These important components are required for assessing environmental conditions and existing technogenic impact, without which it would be impossible to conduct an environmental resilience assessment and assess ecological risk. Although, it is necessary to note that the data obtained through analysis of unclassified space-based images of the research area and unclassified information product derived from national security systems data require further processing which, in turn, requires additional in situ observations to confirm location of sites and other information. Such observations are less time-consuming and less expensive than detailed in situ measurements. Based on the aforementioned facts, we can conclude that the data obtained through analysis of unclassified space-based images of the territory and unclassified information

Figure 23

product derived from national security systems data was of utmost importance to performing the tasks of this and future research. An example of the additional detail obtained from unclassified information obtained from national security systems is shown in Figure 24. The oil structures, waste dumps, specific vegetation type, and pipeline location were all unobtainable from interpretation of civilian satellite images such as SPOT (see bottom of the Figure 24). With this improved information, the risks of the production pads are better described from both the stressor (waste areas defined) and receptor (vegetation types delineated).

Also, the time series derived from information obtained from space-based images for various time periods provide an opportunity to study dynamics of many processes; for example, we can monitor the development of such processes as spring flooding and changes in landscape features and assess the impact provided by infrastructure development. Figure 4 which showed the change in a production area lake is an example of such monitoring. Such information is of great importance for recommendations designed to assist in planning future economic development in the research area and adopting ecologically and economically “correct” management decisions.

Figure 24

5. POLICY RECOMMENDATIONS

5.1. RISK ASSESSMENT AS A TOOL FOR MANAGEMENT, REGULATION, AND REGULATORY REFORM

Risk assessment is a new and important tool for environmental management. One of the main functions of risk assessment is to allow the environmental managers and interested parties to determine the perceived problem, the areas of greatest risk, acceptable levels of problem solution, and prioritize the activities for risk management.

One of the strengths of risk assessment is that it can compare the potential effects of different technologies. For example, in the Priobskoye region, new coated pipes will have a different rate of potential breakage than older uncoated pipe. Risk assessment can also highlight the areas of the new pipeline that may have higher failure rates and are thus most at risk of a spill. This will allow managers to determine what level of cleanup equipment and expertise needs to be available to reduce the potential impact to an “acceptable” level. The acceptable level may be determined through regulations; for example, a certain water quality level that cannot be exceeded for hydrocarbons. Or it may be a local determination of what level of cleanup is acceptable.

In addition, risk assessment enables comparison studies to be performed. The risk of an oil spill from exisiting uncoated pipeline may be much higher than from newer coated pipe. The environmental managers may decide that to mitigate the risk, the highest priority is to use new technology (e.g., coated pipeline and separation of oil from water). However, current regulations may discourage or prohibit technologies with less environmental risk (such as separation of oil and water at the well site with reinjection of the separated water into the aquifer). Risk assessment methodology can compare the risk (e.g., number and quantity of spills and area affected) of using no oil and water separation and uncoated pipe versus oil and water separation and coated pipe. This may provide environmental managers with better information in writing regulations.

Risk assessment does not set regulations, but rather provides information to decision makers on the components of greatest potential risk. With development, there will be environmental impact. It is up to the individuals and regulators concerned to determine what is an acceptable risk.

6. FUTURE USES AND USERS

There are many areas of oil exploration and development in the arctic and subarctic besides the Priobskoye region highlighted in this study. The risk assessment methodology presented in section 3 is applicable to other regions, but the specific risks and GIS layers needed to support risk assessment may be different. For instance, the Yamal peninsula in Russia is an oil exploration region. Yamal is in the continuous permafrost zone, as opposed to the subarctic permafrost-free Priobskoye study region. Oil field development in Yamal's ice-rich permafrost conditions requires insulated pads and pipeline support structures to maintain low surface temperature because the melting of ice-rich permafrost causes severe engineering problems and leaves permanent scars on the treeless tundra. Timan-Pechora is another area of significant petroleum activity in the Russian Arctic. Like Yamal it is remote and requires special care and procedures to produce oil in an environmentally sensitive manner. Yamal's and Timan-Pechora's remoteness accentuate the advantage of remotely sensed data, both civilian satellite and NSS.

In the North American arctic, the McKenzie Delta area, east of Alaska's North Slope, has demonstrated petroleum potential and represents a unique environment where extreme conditions dictate special technologies and procedures for all phases of exploration and development. On the Alaskan North Slope itself, the proposed exploration for oil in the Arctic Wildlife Refuge (east of the Prudhoe Bay oil field) is ecologically risky because it may disrupt the primary food source of the indigenous people, similar to the Priobskoye situation. However, in Alaska the primary food source of the Gwich'in Indians is the herds of caribou rather than fish. The caribou are migratory. In the spring the females come down from the mountains to calve on the coastal plain—the part of the Arctic Refuge where the oil deposit is believed to be. The proposed oil field exploration and production, particularly the pipeline, is expected to disturb the caribou and lessen herd production.

Use of satellite data could be of great benefit in this instance. It could be possible, depending upon the database of images available, to track the herd's migration patterns over the past several years. This would be extremely important in determining important feeding, overwintering, and breeding grounds. The cost savings, compared to yearlong field studies with radio tracking, could be enormous. The use of satellite data would also help in production of a GIS with improved information on elevation, permafrost, exisiting structures, vegetation types, etc. The GIS could be used for early geological testing layouts, as well as laying out the location of roads, pipelines, pumping stations, facilities, etc.

An extremely important use of NSS and civilian satellite data in future oil and gas development risk assessments is for retrospective analysis. The NSS images may provide information on what the terrain was like over the past decades (baseline information), and in so doing provide important information on mitigation issues. In cases of past oil spills that have not been cleaned up, the images could provide important information on how fast and well the environment can (or if it can) repair itself. NSS and civilian satellite data would also show how quickly disturbed areas can revegetate after a disturbance such as clearing for road construction. Because of the slower growth rate of vegetation in cold areas, these areas will have a much slower rate of natural restoration than will areas in warmer regions with sufficient moisture. These are all important issues to understand when determining the level of restoration that will be needed in the event of a spill, or upon decommissioning of facilities.

Probably the most important aspect for future use of satellite data is in preparing maps and GIS databases with ever-greater detail. With improved data and the growing ability of modeling we will be able to better predict the impact of exploration, construction, operation, and restoration activities on the environment. Within the near future, it will be relatively easy to model oil and gas movement between ground, air, and water and thereby predict the impacts on the local wildlife, vegetation, and air, water, and soil quality. We are using the NSS for the first time on environmental issues. As our modeling abilities improve with regard to predicting transport through different media and ecosystem types, we will make great strides in improving risk assessment.

The specific groups and organizations that may benefit from the results of this and future studies include oil companies, government regulatory agencies, local officials, and other GCC groups. Oil companies are interested in lowering costs while maintaining environmentally safe development activities. The remote sensing methods described here translate into economic benefits, especially for remote and inaccessible regions. In addition to risk assessments, oil companies are especially interested in obtaining higher resolution (5 meter or better) terrain elevation data necessary for engineering studies and interpretation of seismic and other remotely sensed data. They also see utility in archived NSS data for documentation of predevelopment oil field conditions. As discussed in the previous section, government agencies are interested in regulatory reform, including baseline evaluation and monitoring at lower cost. Local officials can use these data and methods in planning for emergency response to oil spills. And because GIS databases hold information at multiple scales, local officials can view local conditions in context with the regional overview. Finally, this project is a roadmap for other groups within the GCC to work cooperatively utilizing each country's unique NSS capabilities.

7. CONCLUSIONS

The findings of the Oil and Gas Subgroup study "Environmental Risk Assessments of Oil and Gas Activities Using National Security and Civilian Data Sources" are:

1. Remotely sensed imagery with between 1- and 2-meter spatial resolution (such as that soon to be available from commercial satellite vendors) is an essential ingredient for a reliable GIS-based environmental risk assessment. This type of imagery can lessen the need for expensive and time-consuming field-collected data and can enable risk assessments to be accomplished more quickly, cheaply, and reliably given the ability to extrapolate high spatial detail into broad-area-coverage SPOT and Landsat scenes.
2. Historical imagery data available only from national security sources are essential to developing accurate information on baseline ecological conditions and change over time. The U.S. and Russian approaches to ecological risk assessment constitute complementary methods of optimized environmental management. Both methods provide a comprehensive picture of threat probability for physical and biological aspects of the environment, and both provide an opportunity to jointly evaluate quantitative, temporal, spatial, and economic features of ecological risk.
3. GIS technology—as demonstrated by the U.S.-Russian Priobskoye GIS database—is an excellent tool for managing and displaying data to be used in risk assessments of oil and gas exploration and production activities in fragile arctic and subarctic ecosystems.

4. Example assessments of the risk to fish, waterfowl, and forests from stressors such as oil spills, soil sprays, and road construction showed the interplay of the dynamic Ob flood plain cycle (freeze, thaw, flood, dry) with the receptor critical intervals (spawning, migration, nesting, and new growth).
5. Cooperation between U.S. and Russian government agencies and oil companies will lessen the environmental impact of oil and gas development. Government regulatory agencies and oil and gas companies will be able to use risk assessment methodology to identify and manage risk in an effective fashion.

8. REFERENCES. REFERENCES

Bukata, R.P., Bruton, J.E., and Jerome, J.H. 1985. Application of Direct Measurements of Optical Parameters to the Estimation of Lake Water Quality Indicators. Report 140, Scientific Series of the National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario.

Carlin, B.P., and T.A. Louis. (1996) Bayes and Empirical Bayes Methods for Data Analysis. Chapman and Hall. New York.

Finkel, A.M. (1990) Confronting Uncertainty in Risk Management. Resources for the Future. Washington, D.C.

George, D.G. 1997. The Airborne Remote Sensing of Phytoplankton Chlorophyll in the Lakes and Tarns of the English Lake District. International Journal of Remote Sensing 18: pp. 1961-75.

Goodman, D. (1997) Population viability analysis: the risk assessment paradigm. In, T. Wainwright and A. MacCall [eds], Salmon Extinction Risk Assessment. NOAA Tech Rept. In Press.

Johnson, R.D. and Kasischke, E.S. 1998. Change Vector Analysis: A Technique for the Multispectral Monitoring of Land Cover and Condition. International Journal of Remote Sensing. In Press.

Kotz, S., N.L. Johnson, and C.B. Read. (1982) Encyclopedia of Statistical Sciences. Wiley. N.Y.

Lo, C.P. 1987. Applied Remote Sensing. Longman, New York.

OECD. 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Paris: OECD.

Ramsey, E.W. and Jensen, J.R. 1990. The Derivation of Water Volume Reflectances from Airborne MSS Data Using in situ Water Volume Reflectances and a Combined Optimization Technique and Radiative Transfer Model. International Journal of Remote Sensing 11: pp. 979-998.

Ramsey, E.W., Jensen, J.R., Mackey, H. and Gladden, J. 1992. Remote Sensing of Water Quality in Active to Inactive Cooling Water Reservoirs. International Journal of Remote Sensing 13: pp. 3465-3488.

Suter, GW, II; Sample, BE; Jones, DS; Ashwood, TL; Loar, JM. (1995) Approach and Strategy for Ecological Risk Assessments for the U.S. Department of Energy's Oak Ridge Reservation: 1995 Revision. ES/ER/TM-33/R2, Lockheed Martin Energy Systems Inc., Oak Ridge, TN.

U.S. Environmental Protection Agency. (1992) Framework for ecological risk assessment. Washington, DC: Risk Assessment Forum. EPA/630/R-92/001.

U.S. Environmental Protection Agency. (1994) Guidance for the data quality objectives process. Washington, DC: Quality Assurance Management Staff. EPA QA/G-4.

U.S. Environmental Protection Agency. (1995) Memo to EPA managers from administrator Carol Browner, EPA risk characterization program. March 1995.

U.S. Environmental Protection Agency. (1996) Proposed Guidelines for Ecological Risk Assessment. EPA/630/R-95/002B.

Yuganskneftegaz and Amoco, North Priobskoye License Area World Bank Environmental Impact Accessment, December, 1995.

APPENDIX A. PROBLEM FORMULATIONAPPENDIX A. PROBLEM FORMULATION

The foundation for problem formulation is the integration of available information on the sources of stressors and stressor characteristics, exposure, the ecosystem(s) potentially at risk, and ecological effects (see figure 1). When key information is of the appropriate type and sufficient quality and quantity, problem formulation can proceed effectively. When key information is unavailable in one or more areas, the risk assessment may be temporarily suspended while new data are collected. If new data cannot be collected, then the risk assessment will depend on what is known and what can be extrapolated from existing information. Complete information is not available at the beginning of many risk assessments. When this is the case, the process of problem formulation assists in identifying where key data are missing and provides the framework for further research where more data are needed. Where data are few, a clear articulation of the limitations of conclusions, or uncertainty, from the risk assessment becomes increasingly critical in risk characterization.

The reason for an ecological risk assessment directly influences what information is available at the outset, and what information must be found. A risk assessment can be initiated because a known or potential stressor may be released into the environment, an adverse effect or change in condition is observed, or better management of an important ecological value (e.g., valued ecological resources such as species, communities, ecosystems, or places) is desired. Risk assessments are sometimes initiated for two or all three of these reasons.

Risk assessors beginning with information about the source or stressor will seek information on the effects the stressor might be associated with and the ecosystems that it will likely be found in. Risk assessors beginning with information about an observed effect or change in condition will need information about potential stressors and sources. Risk assessors starting with concern over a particular ecological value may need additional information on the specific condition or effect of interest, the ecosystems potentially at risk, and potential stressors and sources.

The ecological risk assessment process is by nature iterative. For example, it may take more than one pass through problem formulation to complete planning for the risk assessment, or information gathered in the analysis phase may suggest further problem formulation activities such as modification of the endpoints selected.

To maximize efficient use of limited resources, ecological risk assessments are frequently designed in sequential tiers that proceed from simple, relatively inexpensive evaluations to more costly and complex assessments. Initial tiers are based on conservative assumptions, such as maximum exposure and ecological sensitivity. When an early tier cannot define risk to support a management decision, a higher assessment tier is used that may require either additional data or applying more refined analysis techniques to available data. Iterations proceed until sufficient information is available to support a sound management decision, within the constraints of available resources.

Risk hypotheses are proposed answers to questions risk assessors have about what responses assessment endpoints (and measures) will show when they are exposed to stressors and how exposure will occur. Risk hypotheses clarify and codify relationships that are proposed through the consideration of available data, information from scientific literature, and the best professional judgment of the risk assessors developing the conceptual models. This explicit process opens the risk assessment to peer review and evaluation to ensure the scientific validity of the work. Risk hypotheses are not equivalent to statistical testing of null and alternative hypotheses. However, predictions generated from risk hypotheses can be tested in a variety of ways, including standard statistical approaches.

Successful completion of problem formulation depends on the quality of three products: assessment endpoints, conceptual models, and an analysis plan. Since problem formulation is inherently interactive and iterative, not linear, substantial reevaluation is expected to occur within and among all the products of problem formulation.

Assessment endpoints are "explicit expressions of the actual environmental value that is to be protected" (U.S. EPA, 1992) that link the risk assessment to management concerns. Assessment endpoints include both a valued ecological entity and an attribute of that entity that is important to protect and potentially at risk (e.g., overwintering sites for important fish species, traditional hunting areas). For a risk assessment to have scientific validity, assessment endpoints must be ecologically relevant to the ecosystem they represent and susceptible to the stressors of concern. Assessment endpoints that represent societal values and management goals are more effective in that they increase the likelihood that the risk assessment will be used in management decisions. Assessment endpoints that fulfill all three criteria provide the best foundation for an effective risk assessment.

Potential interactions between assessment endpoints and stressors are explored by developing a conceptual model. Conceptual models link anthropogenic activities with stressors and evaluate interrelationships among exposure pathways, ecological effects, and ecological receptors. Conceptual models include two principal components: risk hypotheses and a conceptual model diagram.

Risk hypotheses describe predicted relationships among stressor, exposure, and assessment endpoint response. Risk hypotheses are hypotheses in the broad scientific sense; they do not necessarily involve statistical testing of null and alternative hypotheses or any particular analytical approach. Risk hypotheses may predict the effects of a stressor (e.g., a chemical release) or may postulate what stressors may have caused observed ecological effects. Key risk hypotheses are identified for subsequent evaluation in the risk assessment.

A useful way to express the relationships described by the risk hypotheses is through a diagram of a conceptual model. Conceptual model diagrams are useful tools for communicating important pathways in a clear and concise way and for identifying major sources of uncertainty. Risk assessors can use these diagrams and risk hypotheses to identify the most important pathways and relationships that will be evaluated in the analysis phase. Risk assessors justify what will be done as well as what will not be done in the assessment in an analysis plan. The analysis plan also describes the data and measures to be used in the risk assessment and how risks will be characterized.

The conceptual model is developed after the initial problem formulation phase of the assessment and is refined as the assessment proceeds. It presents a working hypothesis of how the contaminants of concern at a site might affect the ecological components. The model includes descriptions of the contaminant source(s), the receptor, the exposure pathway(s), and the impacts to the receptor and other environmental components.

Conceptual models should be inclusive in that they should include all sources, receptor classes, and routes of exposure that are of plausible concern. As the risk assessment process continues, the models are refined by eliminating (1) receptors that are not deemed to be suitable assessment endpoints, (2) routes of exposure that are not credible or important, (3) routes of exposure that do not lead to endpoint receptors, and (4) potential sources that are not deemed credible or important. In addition, the conceptual model becomes more specific as particular endpoints and the spatial and temporal scale of the assessment are identified.

The basis for the conceptual models depends on the stage of the assessment and the amount of assessment that has been done before that stage.

- The first conceptual model is based on qualitative evaluation of existing information and expert judgment. It should be conservative in the sense that sources, pathways, and receptors should be deleted only if they are clearly not applicable to the site.
- The participants in the assessment process can apply professional judgment and managerial authority to modify the draft conceptual model presented by the assessment scientists. For example, the parties may decide that the results of the screening assessment are not based on data of sufficient quality and quantity to justify

deleting media or receptors. Some receptors may be eliminated because they are not judged to be sufficiently important or sensitive or not sufficiently related to the remedial decision.

STRESSORS

All conceptual models begin with stressors. Each distinct stressor should be identified in a separate box. Types of stressors should be distinguished when they are distinctly different in form or composition or when they can affect a receptor in different manners or in situations that would result in different transport routes.

ROUTES OF TRANSPORT

The conceptual model should identify the routes by which stressors are transferred to ambient media to which receptors may be exposed. The specific routes of exposure should be described. For example, the transport from sources to surface water should be identified as occurring in leachate emerging at seeps, in leachate mixed with groundwater entering streams reaches, by erosion of contaminated soil, etc. (Suter et al., 1995).

The routes of transport for ecological conceptual models do not normally include deep groundwater transport because it does not contribute to surface water contamination and because wildlife do not drink well water.

Except for movement into downstream areas, these conceptual models do not include fate processes that remove contaminants from the system (e.g., degradation and sequestration) because these conceptual models are intended to illustrate, in a simple fashion, how ecological receptors come to be exposed rather than illustrating the fate of the contaminants.

EXPOSURE MEDIA

The conceptual model should identify the media that are known to be significantly contaminated, are hypothesized to currently be significantly contaminated, or are predicted to be significantly contaminated in the future. If possible, significance of contamination should be based on the results of an assessment that compares screening of measured contaminant concentrations against ecotoxicological benchmarks and background concentrations. Alternatively, modeled concentrations may be screened in the same way. In the absence of measured or modeled concentrations, expert judgment should be conservatively applied. A medium should be included in the model if any chemical in the medium is retained by the screening process or any chemical is judged to potentially be present at significant concentrations.

In some cases, the contaminated medium is also the waste (i.e., the source of the contaminant chemicals). This would also be the case for any waste sumps that are treated as receptor ecosystems rather than as sources. In such cases, the source box is simply combined with the soil, water, or sediment box.

ROUTES OF EXPOSURE

The conceptual model should identify the routes of exposure that are assumed to result in uptake of chemicals from contaminated organic and inorganic media. The number of routes of exposure is limited to those that are deemed to be important for the endpoint receptors. The following points should be considered.

- Fish, aquatic invertebrates, and aquatic plants are assumed to be exposed to contaminants in water. Conventionally, most risk assessors have assumed that dietary exposures are negligible, and that is likely to be true for most chemicals. For example, the National Ambient Water Quality Criteria for Protection of Aquatic Life are based on toxicity tests in which organisms are unfed or fed clean food. This is reasonable given the relatively high rate of exposure of organisms to chemicals in the water that pass their respiratory surfaces and the fact that most chemicals are not highly bioaccumulative and do not biomagnify.
- Dietary exposures should not be routinely included for fish or aquatic invertebrates. Dietary exposure is important for a few long-lived and biophilic chemicals such as polychlorinated biphenyls (PCBs) and dioxins and may be important for a wider variety of chemicals than is currently recognized. Fish body burdens integrate dietary and direct aqueous exposures, but toxicity information is not standardized or available for exposures to most chemicals in terms of body burdens. Therefore, dietary exposures should be included only if the assessors have reason to believe that

they are a significant route and have a method for assessing risks due to that route.

- Benthic invertebrates are exposed to sediment pore water and whole sediment. Although the graphic version of the conceptual model need not depict this distinction, it is important to include in the narrative. Although EPA's sediment quality criteria are based on exposure to the aqueous phase of sediments (i.e., pore water), the evidence is strong that some benthic invertebrates are significantly exposed to a variety of chemicals by ingestion of sediment particles. Pore water concentrations cannot be reliably estimated from whole sediment concentrations for chemicals other than neutral organic compounds, but pore water may be extracted and analyzed. Therefore, it is important to characterize risks due to both modes of exposure.
- Wildlife exposure routes usually include ingestion of food, drinking water, and incidental soil ingestion. Soil ingestion may be excluded for species that have little exposure to soil (e.g., predatory species of birds).
- Dermal exposure of wildlife should not normally be included. Unlike humans, birds and mammalian wildlife are covered with feathers and fur. These coverings exclude most dermal exposures. However, they create another route of exposure: grooming and preening, which contribute to incidental soil ingestion. Amphibians are likely to experience significant dermal uptake, but neither exposure models nor toxicity data are available to address this route and receptor for terrestrial exposures. Aqueous dermal exposures for amphibians are equivalent to respiratory exposure of fish in that they are assumed to be due to direct uptake of dissolved chemicals through the respiratory epithelium, which is the skin.
- Respiratory exposure of wildlife is not normally included because there is usually not a significant concentration of contaminant chemicals in the air.
- Plants, soil invertebrates, and soil microbes are assumed to be directly exposed to whole soil.

- In cases where shallow groundwater is contaminated, plants are exposed to that water.

RECEPTORS

The receptors presented in the conceptual model should be those that have been proposed to be or designated as assessment endpoint receptors (organisms, populations, communities, or ecosystems).

Ecosystems are assessment endpoints if the properties to be protected are ecosystem properties. This is the case for wetlands, which are protected for their habitat value to wetland-dependent species and their roles in nutrient retention and cycling and hydrologic regulation. If significant areas of wetlands are present (i.e., areas sufficient to significantly contribute habitat, nutrient cycling, and hydrologic regulation functions to the watershed in which they occur), they should be included in the graphical model and their size, type, and assumed functional properties defined in the narrative. A component of an ecosystem that is valued for its functional properties rather than its community or population properties may also be considered an ecosystem-level endpoint.

Fishes, benthic macroinvertebrates, soil invertebrates, and upland plants are community-level assessment endpoints. That is, the species richness and abundance of the communities are the endpoint properties rather than properties of the component populations. Cases where components of the community such as benthic-feeding fish or trees are believed to differ in their susceptibility should be distinguished in the conceptual model. The model should describe each community or subcommunity both in biological terms (e.g., all benthic macroinvertebrates) and in operational terms (e.g., all invertebrates collected by a Surber sampler and retained by a 1-mm mesh screen).

Most wildlife and commercial or recreationally important fish are population-level assessment endpoints. The endpoint properties are abundance and production of individual populations. The populations used are chosen to represent a particular trophic group and taxonomic class (i.e., fish, birds, and mammals). The conceptual model should identify these receptors both in terms of the species and location of the population (e.g., broad whitefish in Ob River) and the group that they represent (e.g., subsistence fishery). Some trophic/taxonomic groups will have more than one representative species (e.g., kingfishers and osprey for piscivorous birds). Others, such as reptiles, may have none because of the lack of toxicological information concerning those species. The narrative for these receptors should indicate why the representative species was chosen and exactly what other species it represents.

INDIRECT EXPOSURE AND EFFECTS

The generic conceptual model includes indirect routes of exposure (i.e., food web transfers) but not indirect effects. An endpoint may be affected indirectly through toxic effects on lower trophic groups, by toxic effects on groups that provide physical habitat, or by other mechanisms. The importance of explicitly including indirect effects depends on the nature of the ecological relationship that causes the indirect effect and the relative sensitivity of the groups involved. For example, it is assumed for most chemicals that aquatic invertebrates and fish are more sensitive than the algal community. Therefore, while that trophic relationship should be acknowledged in the conceptual model, it should be made clear that the indirect effects on fish and invertebrates of direct toxicity to algae are not included (if that is the case). The indirect effect that is most likely to be of concern in aquatic ecosystems is the reduction in food for fish that is due to toxic effects on invertebrates. Planktonic crustaceans and benthic insects are often more sensitive than fishes, and benthic invertebrates are more exposed to contaminated sediments than are fish.

APPENDIX B. DESCRIPTION OF SITE 1 AND OVERVIEW GIS LAYERS

To facilitate reference to the digitial data, a table correlating the digital file names of the GIS layers of the Overview Area (see Figure 7) with their contents is given below.

Table 2. 1:250,000 Scale GIS of Overview Area

4.6.4.3 Export	4.6.4.3 Attribute Name	4.6.4.3 Description
ab_bound	none	Aboriginal boundaries
bnd_utm	none	Boundary of overview area
bridges	none	Bridges
habitat	type	Winter fishing, duck hunting
"	desc	Fur bearer hunting
density	land	Density of vegetation
"	forest	Forest
"	density	Density of
helopads	none	Helocopter pads
lakes	Rus	Lakes
oil_clust	number_of	Oil clusters
pipeline	Rus	Pipeline
pump_sta	U.S.	Pump station
lakes	none	Lakes
pwrline	none	Pwrline
river	riv	River
roads	type	Roads
"	type_descr	Type of road
setlmnt	name	Settlement
"	population	Population
"	Rus	Russian
streams	seasonal	Streams
veg	geology	Geology
"	soils	Soils
"	age_of_dep	Age of deposit
"	veg_type	Vegetation type
"	land	Streams

A table correlating the digital file names of Site 1 layers with their contents is given below followed by: 1) a description of the main categories covered by the GIS Layers: (Terrain, Hydrology, Meteorological Conditions, Infrastructure, Fish, Waterfowl, and Forests), and 2) a resiliency analysis of Site 1.

Table 3. 1:25,000 Scale GIS of Site 1

4.6.4.3 Export	4.6.4.3 Attribute	4.6.4.3 Description
bldgs	none	Buildings
bridges	none	Bridges
cnt_area	none	Containment area
drill_eq	none	Drilling equipment
ex_equip	none	Exploration equipment
exp_site	none	Exploration site
“	type	Numeric attribute for well or pit, where, well=1 and pit=2
“	desc	Well or pit designation
helopads	none	Helo pads
lakes	none	Lakes
new_pipe	none	Proposed pipeline (AMOCO)
oil_tank	none	Oil tanks
pipeline	none	Existing pipeline
prod_pad	none	Production pads
pump_sta	none	Pump stations
pwrline	none	Circles depict location of tower
river	type	Main river channel
road_pav	none	Paved roads
road_tmp	none	Temporary roads
road_upv	none	Unpaved roads
sand_ple	none	Sand piles
sand_qu	none	Sand quarry
slgd_ln	none	Sludge line
slgd_pit	none	Sludge pit
stlmnts	desc	Settlements by name
streams	none	Streams
veg	vegtype	Type of forest-type vegetation
“	vegdensity	Density of forest-type vegetation
“	vegtype_num	Numeric designation for vegetation
“	vegdens_num	Numeric designation for density
veg_rus	vegetation	Land cover
“	plants	Latin names for species in region
wetlands	Obj_type	Swamps
“	Aux_info	Mosses and sparse forest
wste_dup	none	4.6.4.3 Waste dump

Table 3. 1:25,000 Scale GIS of Site 1 (continued)

Export File Name (.e00)	**Hydrological Data Used in Risk Analysis**	**4.6.4.3**
speed		Direction of main waterways in the Region (Ob River, Great Salym and Small Salym channels) is depicted by curved lines.
“	speed	River flow speed, in m/sec
“	debit, m^3/sec	Ob River water discharge
ob.dbf	level	Flood level readings above zero mark per decade (starting in May)
	Data on Fish	
ichthyol	infrequent	Rare fish species (Russian names)
“	producer	Economically valuable fish species (Russian names)
“	producer_	Economically valuable fish species (Latin names)
“	migr_inf	Pathways and periods of migration for rare fish species
“	migration_	Migration of economically valuable fish species
“	comp_inf	Content of rare fish populations (%)
“	compositio	Composition of species for economically valuable fish
“	compos	Quantitative composition of economically valuable fish species in a sample catch
“	fish_nesti	Spawning grounds for economically valuable fish species
	Data on Waterfowl	
density	density	Waterfowl population density during migration and prior to migration periods, birds per km^2
“	name_and_d	Composition of waterfowl species (Russian names), in %
density2	density	Summer waterfowl population density, birds per km^2
“	name_and_d	Composition of waterfowl species (Russian names), in %
birds	birds	Waterfowl nesting and feeding grounds

TERRAIN

All landscape types of the Mid-Ob region are represented in the test site area. The main landscape feature is the Ob River. The Ob riverbed has a meandering route with wide distance between tributaries, thus forming a large number of lakes (sors). The width of the Ob flood plain in the test site area reaches 20 kilometers. Several distinctive sections are represented in the flood plain: frequently flooded, occasionally flooded, and rarely flooded areas. Relative height variations are within 5-7 meters and up to 10 meters. The flood plain is covered with grass meadow and marsh vegetation with almost no standing trees. The flood plain has numerous meandering streams, sors and marshes. The landscape features include terraces, sand spits, and bank arches, as well as "ridges" - erosion remnants of river terraces. The flood plain lakes are generally small with from several meters to several kilometers in diameter and usually up to 5 meters deep. Sedimentation occurs in a form of sand banks that consist of fine sands and sandstone, various types of loams, silt, clay and pit; clay and pit areas are located in less actively flooded areas.

The terrace in the test site area is a swampy flat area that is almost completely covered with forest and numerous small and shallow lakes. Terrace boundaries are along the left bank of Maliy Salym river with elevation over the Ob river of 1.5 meters.

HYDROLOGY OF THE TEST SITE AREA

The rivers in the test site area are characterized by slow current due to a flat landscape, although the Ob River is the largest river in Russia with annual water discharge in the research area reaching 8,000 m^3/sec. As mentioned earlier, the Ob River is a meandering river that forms numerous lakes and ponds. The Ob River has a large number of small and large tributaries; the largest tributaries in the test site area are Bolshoy and Maliy Salym rivers. In turn, tributaries have water inflow from ground and surface waters. During spring flood season, water level in the Ob River increases significantly due to the inflow of snow and ice melt water. Water level in the Ob River usually increases by 5-7 meters during normal spring flood seasons. In years of increased flooding, the water level increase can exceed 10 meters which results in flooding of the entire flood plain area. All small and large water reservoirs also overflow and cause additional flooding. Water discharge increases also due to extensive rainfalls that are common during this season. We should also note the development of small shallow lakes (sors) in the flood plain area during this season. Sors are temporary lakes that are created during the early stages of spring flood season in late April or early May and remain filled with water till late July or early August. Sors are usually connected with rivers by narrow flood streams and serve as common areas for fish spawning grounds.

Late October marks the beginning of water freezing. Ice blocks water streams resulting in increase in water levels. A decrease of oxygen concentration levels is observed due to ice formation processes.

The rivers in the test site area have different depth levels. According to our data, generally, the Ob River freezes from 1 to 1.5 meters deep and flood plain rivers freeze up to 1 meter (average depth of ice is approximately 0.7 meters). Ice depth in lakes is greater than in rivers and constitute approximately 1.2 meters, in marshes - 0.5 - 1.2 meters. An average ice cover of water reservoirs lasts for 180-190 days.

METEOROLOGICAL CONDITIONS IN THE RESEARCH AREA

According to existing data, the area is characterized primarily by western winds. Average wind speed is 3-5 m/sec. Maximum wind speeds are observed during the spring and fall seasons and could be as high as 15 m/sec.

Air temperature in the research area reaches its maximum in July (average monthly temperature of 17°C) and minimum readings in January (average monthly temperature of -20°C). An average period of temperature above 0°C is 160-170 days between the months of May and October. Ground temperatures have the highest readings in July with variation between the minimum readings of -2°C up to the maximum 49°C which constitutes an average temperature of 19°C. The lowest ground temperature is observed in the winter, it is -23°C in January.

Average annual precipitation in the research area is approximately 550-650 mm. Maximum monthly precipitation is observed in July and August (approximately 70-75 mm per month), and minimum precipitation is observed in late winter (with average precipitation of up to 40 mm per month).

Snow cover in the research area is developed in October and melts down in late May. Average maximum snow depth reaches 45 cm in February and March. The protected areas (for example, forested areas) can have snow depths of as much as 70 cm.

INFRASTRUCTURE

Currently, the main infrastructure sites are located on the left bank of the Ob River outside the flood plain terrace. Such sites include oil well clusters, central oil collection unit, management offices and personnel housing, as well as export and mainline pipelines and access roads. According to the Priobskoye oil field development plan, construction of new clusters, oil collection systems, pump station (on the Ob's left bank), new pipelines, access roads, and management sites is planned for the flood plain section of the test site area.

RARE AND ECONOMICALLY VALUABLE FISH

The Ob basin serves as the habitat for several dozen fish species, including the following rare and economically valuable species:

Sturgeon family, Acipenseridae

- Siberian sturgeon, Acipenser gueldenstaedtii
- sterlet, Acipenser ruthenus

Whitefish family, Coregonidae

- white salmon, Stenodus leucichthys
- muksun (whitefish), Coregonus muksun
- peled (whitefish), Coregonus peled
- whitefish, Coregonus lavaretus

Salmon family, Salmonidae

- taimen, Hucho taimen

Carp family, Cyprinidae

- ide, Leuciscus idus
- roach, Rutilus rutilus
- dace, Leuciscus leuciscus
- common crucian, Carassius carassius
- bream, Abramis brama

Cod family, Gadidae

- burbot, Lota lota

Pike family, Esocidae

- pike, Esox lucius

Perch family

- perch, Perca fluviatilis
- ruff, Gymnocephalus cernuus
- pike perch, Stizosteduion lucioperca

Major fish species are described as follows:

Rare fish.

1. Sturgeon (Siberian sturgeon, sterlet):

Siberian sturgeon is a large fish with late maturity that is of high value due to its tasty meat and caviar. Sterlet is also a tasty fish and in fact is a miniature sturgeon. Sturgeon species are not present in the test site area from early January through early April due to high mortality effects. Sturgeon is not present in the Ob River from early April through June, although sterlet can be found. Spawning migration of sturgeon begins in July - October with peak levels reached in September; reverse post-spawning downstream migration of last year spawning sturgeon begins along with sturgeon offspring flow migration. Spawning migration of sturgeon ends in November - early January, while flow migration of spawning sturgeon and offspring continues.

2. Whitefish (white salmon, muksun, peled, and whitefish):

Major and most valuable whitefish species in the test site area are muksun, sturgeon, and sterlet. Muksun are migratory species that spawn in the upper Mid-Ob region and spend the rest of its life cycle in the Ob and Tazovskaya bays. Whitefish species are not present in the Ob River from early January through early April due to high mortality effects. Spawning migration of white salmon, muksun, peled, and whitefish begins in July - October with peak levels reached in September; reverse post-spawning downstream migration of last year spawning whitefish species continues and offspring flow migration ends. Spawning migration of whitefish species practically ends in November - early January along with flow migration of spawning whitefish species and its offspring. It’s necessary to note that the main Ob riverbed is not the only habitat for the aforementioned species. For example, according to our data, the quantity of these species in the Ob tributary Bolshoy Salym is 30-40% of the total quantity of whitefish species in the Ob River. Peled can be observed from May through October in Yelykova river (approximately 1.5%) and flood plain lakes (approximately 0.14%). Small quantities of sterlet species can be observed in Maliy Salym river throughout the year (approximately 0.1% in the spring and fall seasons) along with peled that can reach 3.75% in the summer and fall seasons.

Economically valuable fish

Economically valuable fish (ide, dace, roach, pike, and perch). Pike, as representative economically valuable species, are caught due its high food value. Pike are widespread in the test site area and account for approximately 20% of catches in all lakes and rivers with the exception of those with high fish mortality effects in the winter period. Economically valuable fish are not observed in the Ob River from early January through early April due to high mortality effects.

The Ob River:

In early April through June, migration is observed via the Ob main riverbed from wintering grounds to spawning grounds. In June - mid-July, a limited quantity of economically valuable fish remains in the river. In July - October, the majority of fish migrates to the main riverbed which corresponds with the beginning of water level decrease followed by wintering migration. Wintering migration ends in November - early January and fish leaves the main riverbed for wintering grounds.

Yelykova river:

Early January - early April - possible availability of favorable wintering grounds and subsequently fish are present;

Early April - June - spawning and offspring development grounds for the majority of economically valuable fish. The ratio of fish quantity per species (in percent) of dace, ide, roach, pike, and perch is 65.9/10.0/15.4/3.0/0.5;

June - mid-July - a significant part of mature fish and offspring migrate to feeding grounds in the flood plain. Relative quantity ratio for ide, dace, roach, and perch is 1.5/74.3/11.3/1.5%;

July - October - the majority of fish migrate to tributaries due to the beginning of water level decrease;

November - early January - wintering migration ends, majority of fish migrate to main wintering grounds.

Other tributaries of Maliy Salym:

Early January - early April - fish are absent due to unfavorable wintering conditions;

Early April - June - spawning and offspring development grounds for the majority of economically valuable fish;

June - mid-July - a significant part of mature fish and offspring migrate to feeding grounds in the flood plain. Average concentration of offspring in the Gorodishenskaya river estuary is 141 species/m^3, Varovaya river - 171 species/m^3, Sogrina tributary - 114 species/ m^3, Goreliy Log river - 90 species/m^3, with average concentration for all sites of 66 species/m^3;

July - October - the majority of fish migrate to tributaries due to the beginning of water level decrease;

November - early January - wintering migration ends, majority of fish migrate to main wintering grounds.

Flood plain reservoirs:
Early January - early April - fish are absent due to unfavorable wintering conditions;
Early April - June - main flood plain tributaries could serve as spawning and offspring development grounds for some economically valuable fish;
June - mid-July - intensive feeding of majority of mature economically valuable fish and its offspring. Relative ratios of fish per species (in percent) for ide, dace, roach, pike, and perch are 20.7/62.5/5.2/0.14/11.2/0.14%, while the catch ratios are 47.2/18.9/3.8/29.0/0.7/0.3 %;
July - October - Small quantity of offspring and mature fish can be observed in the flood plain tributaries and sors;
November - early January - all fish migrate off the flood plain.

Maliy Salym river:
Early January - early April - possible favorable wintering conditions;
Early April - June - spawning migration routes; spawning and offspring development grounds for majority of economically valuable fish;
June - mid-July - significant part of mature fish and offspring migrate towards feeding grounds in the flood plain. Relative ratios for ide, dace, roach, pike, and perch is 24.1/15.5/39.6/0.5/4.8/7.0%;
July - October - the majority of fish migrate to main tributaries and estuaries due to the beginning of water level decrease;
November - early January - wintering migration ends, majority of fish migrate to main wintering grounds.

WATERFOWL

During the first phase of this research, initial data on waterfowl species, population density, nesting and feeding grounds, and transmigration stopovers were analyzed. All data were incorporated in a map. Considering the existing climate (geographic) zone of the test site areas (for waterfowl), it seemed appropriate to divide a calendar year into three periods: winter (October - April), summer (June - August), and spring-fall (May and September). Winter period should be considered non-informative for waterfowl due to south-bound migration of waterfowl species. Therefore, two periods have been analyzed - summer (June - August) and spring-fall (May and September).

There is a significant number of waterfowl species present in the test site area, especially if we also consider waterfowl species that migrate through the area, although it's impossible to list all species due to the lack of applicable data. Thus, the population density data table describes only the most populous and common species that are of greatest interest to this research (such as

Swan and Gray Goose).

Table 4. Conditional list of waterfowl species in Priobskoye oil field area:

No.	Species English Name	Species Latin Name
1.	Mallard	Anas platyrhynchos
2.	Pintail Duck	Anas acuta
3.	Crackling Teal	Anas querquedula
4.	Whistling Teal	Anas crecca
5.	Widgeon	Anas penelope
6.	Gray Teal	Anas strepera
7.	Soksun	
8.	Crested, Marine Diving Duck	Aythya fuligula, marila
9.	Goldeneye	Bucephala clangula
10.	Calling Swan	Cygnus cygnus
11.	Gray Goose	Anser anser
12.	White-front Goose	Anser albifrons
13.	Hook-nosed Scoter	Melanitta fusca
14.	Black Scoter	Melanitta nigra
15.	Merganser	Mergus merganser
16.	Smew	Mergus Albellus
17.	Long-haired Merganser	Mergus serrator
18.	Peeping Goose	Anser erythropus
19.	Bean Goose	Anser fabalis
20.	Red-throated Brant	Branta ruficollis
21.	Chirping Spoonbill	Anas crecca
22.	Shoveler	Anas clypeata
23.	Red-nosed Diving Duck	Netta rufina
24.	Red-headed Diving Duck	Aythya marila
25.	Arctic (Black-throated) Loon	Gavia arctica
26.	Red-throated Loon	Gavia stellata
27.	Gray-cheeked Grebe	Podiceps grisegena
28.	Red-necked Grebe	Podiceps auritus
29.	Long-eared Grebe	Podiceps nigricollis
30.	Gray Heron	Ardea cinerea
31.	Bittern	Botaurus stellaris
32.	Black Stork	Ciconia nigra
33.	Tundra Swan	Cygnus bewickii

Table 5. Population percentage of major waterfowl species in the Priobskoye oil field area:

No.	Species English Name	Species Latin Name	%
1.	Mallard	Anas platyrhynchos	8
2.	Pintail Duck	Anas acuta	14
3.	Crackling Teal	Anas querquedula	8
4.	Whistling Teal	Anas	8
5.	Widgeon	Anas penelope	8
6.	Gray Teal	Anas strepera	5
7.	Soksun		5
8.	Crested, Marine Diving Duck	Aythya fuligula, marila	8
9.	Goldeneye	Bucephala clangula	8
10.	Calling Swan	Cygnus cygnus	3
11.	Gray Goose	Anser anser	10
12.	Other		15

The Ob flood plain serves as the most important habitat for migratory birds in the spring-fall and summer seasons, as well as the nesting grounds for local species such as various ducks and swans. The most common duck species represented in the area are Pintail Duck (Anas acuta), Mallard (Anas platyrhynchos), Crackling Teal (Whistling Teal) (Anas querquedula), Crested, Marine Diving Duck (Aythya fuligula, marila), and Goldeneye (Bucephala clangula).

The following are the most common waterfowl species in the Priobskoye oil field area:

Mallard (Anas platyrhynchos).

It's a bright-feathered duck that inhibits the banks of internal water reservoirs; its nesting grounds are in coastal brushwood, usually directly on ground surface. In the wild, mallard can be easily scared away. Common mallard is an ancestor to domestic ducks; it's a large duck (up to two kilograms). Mallard lives in large flocks of its own species, although easily coexists with other groups of waterfowl. It has various vegetable and organic diet, in other words, it consumes everything it can digest. The main diet is water plankton that Mallard consumes by filtering water through its bill, as well as water and coastal vegetation.

Pintail Duck (Anas acuta)

A relatively common duck. A long needle-shaped tail is characteristic for both male and female species. It nests in grass on the ground adjacent to water reservoirs. In the winter, Pintail

Duck migrates to southern warm countries.

Whistling Teal (Anas crecca)

Whistling Teal is the smallest European duck. Its wintering grounds are located in the ocean coastal areas, usually along estuaries of large rivers.

Crackling Teal (Anas querquedula)

Crackling Teal is slightly larger than Whistling Teal, it inhibits freshwater reservoirs and nests in tall grass.

Widgeon (Anas penelope)

Widgeon is smaller than a common Mallard. Male Widgeon can be easily recognized by a red-brown head with a pale-raddle line. Male species communicate through distinctive whistling. Widgeon nests in marshes and peat-bogs, as well as along small quiet rivers and lakes without much vegetation. Widgeon's diet includes worms, seeds, young growth and roots of submerged and semi-submerged plants. In the fall, Widgeon migrates to meadows and fields where it feeds on young grass and sedge. From late May through mid-June female Widgeon lays 7-11 eggs in nests hidden in bushes or dry grass, usually close to water. During molting season (late June - mid-July), birds shed all wing-feathers and are unable to fly. Mature birds and offspring are particularly defenseless during molting season. The fall migration is directed to Southern Europe and Northern Africa.

Crested, Marine Diving Duck (Aythya marila, fuligula)

Marine Diving Duck differs from Crested Diving Duck by the lack of elongated feathers on its head that form a crest. Diving Duck prefers to live close to water reservoirs. Preferable nesting grounds are located along freshwater and saltwater lakes in reed bushes or in dry reed surrounded by dense vegetation. The nest could be built on dry reed in dense vegetation or on a floating island of vegetation. Average clutch is from 7 to 12 eggs between late May through mid-June. Molting season lasts from late June through mid-July when the birds shed all wing-feathers and are unable to fly and become particularly defenseless. Diving Duck eats larva, small crustaceans, and fish. The birds find food by diving to the bottom of lakes, ponds, streams, and rivers.

Goldeneye (Bucephala clangula)

Goldeneye is a diving species that is common in the same areas as Marine Diving Duck. Goldeneye often nests in burrows and hollows.

Calling Swan (Cygnus cygnus)

Calling Swan belongs to a sub-family of geese (Anserinae) of a goose-form order. Swan reaches 1.5 meters in length, common color - white. The base of its black bill is lemon-colored. These species can not be considered endangered or disappearing, although they are very rare and hunting of Calling Swan is prohibited in the majority of Russian territories. Swans live in pairs primarily on large remote lakes with clear water and banks covered with sedge and reed. Nesting season starts in mid-May. Swan usually nests in shallow waters or on lake islands. The nest is a well-camouflaged pile of vegetation with an average clutch of 4-6 eggs. An average number of offspring in the Priobskoye oil field flood plain is 3.1. During molting season in July and early August mature Swans shed all wing-feathers and are unable to fly. Swan gather on large lakes in preparation for the fall migration season. Swan's diet primarily includes water plants, it feeds by lowering its head and neck into the water, although it doesn't dive.

Gray Goose (Anser anser)

Gray Goose is the largest species of wild geese in Europe. Gray Goose is an ancestor to a number of species of European domestic geese. Gray Goose's habitat is along freshwater reservoirs. Geese nest in pairs on lakes surrounded by vegetation or on grassy marshes in remote and inaccessible area. The nest is built of reed stems and other plants. There are various nesting options: in a dry place on high ground, lake islands, and floating islands of branches and leaves. An average clutch is 4-6 eggs. During molting season, Gray Goose sheds all wing-feathers and become defenseless (unable to fly). Gray Goose is a night-loving bird (feeds at night, rests on shallow waters during the day). Its diet includes submerged and semi-submerged plants in lakes and other reservoirs.

Waterfowl species arrive in the area in May and begin nesting shortly thereafter. Other species fly through the area with stopovers. Therefore, the density of waterfowl population differs dramatically. The highest density levels are observed in May and September or the time of transmigration, stopovers and feeding prior to migration. Such species as Peeping Goose, Red-throated Brant, Black Stork, and Tundra Swan are registered in the Russian Red Book of endangered species. South-bound migration begins by late September after extensive feeding in August and September. Migration routes for the majority of swans, geese, and ducks lay along the Ob River plain, including the test site areas. It's necessary to note that transmigration of birds (the beginning and end of migration) is a lengthy process, therefore the birds are scattered throughout vast territories. Molting season begins in July-August. Many birds shed feathers close to nests during raising of offspring, while non-mature and nestless birds could migrate to special molting grounds such as highly productive lakes with plenty of fish and without annual sedimentation or Ob River tributaries where submerged plants serve as an abundant food source. According to the existing data, birds gather along tributaries, lakes, and ponds. According to our observations, large flocks were located along Balinskaya river and Labytbor and Maliy Salym tributaries. The areas of dense waterfowl population and nesting grounds were determined using the data obtained through observations and cartographic materials such as topological, vegetation, and hydrological maps as well as space-based imagery for this area in various seasons. The areas marked on the map do not mean that waterfowl is completely absent in other areas, whereas it means that such areas have the highest concentration of waterfowl and non-marked areas should not be considered for this research. Despite such precise mapping of dense areas, it's necessary to remember that birds could freely migrate along the flood plain during transmigration season and in search of better nesting and feeding grounds. Presently, there's no information on nesting colonies of geese, although there's evidence of such colonies which allows us to determine the location of possible nesting areas with greater precision.

FORESTS

Forests in the test site area are located almost entirely on high ground on terraces and ridges that surround the flood plain. Usually, the area is characterized by mixed forests comprised of such tree species as birch, aspen, Siberian pine (cedar), and spruce that are growing on mineral soils in areas with high moisture content and sufficient drainage due to loamy alluvial sediments and closed crown cover.

Generally, major dominant tree species in the research area are represented by Siberian pine, birch, and aspen that are growing on elevated terraces and ridges that surround the flood plain. Such dominant tree species are characterized by relatively tall stems (exceeding 30 meters) and an almost closed crown cover. Tree age can exceed 200 years. In addition to Siberian pine (cedar), other dominant tree species include birch and aspen that create favorable growth conditions for coniferous young growth. Linnea, hypnum moss, mountain cranberry, whortleberry, and crab apple represent the ground-level layer.

The flood plain section of the test site area is represented mainly by meadow and marsh vegetation, although forest plantations with aspen and birch as dominant tree species can be observed in elevated areas with sufficient drainage.

RESILIENCE RESULTS FOR SITE 1

For the following receptors--rare and economically valuable fish--resilience will be determined by the presence of a number of species at a stated time in a certain point (density). The possibility of stress situations is relatively high in the area under review and cannot be limited to the aforementioned hypothetical situations. For example, there's a real threat at any point of accidents related to tankers that sail along the Ob River, as well as stress situations caused by fuel spills from fuel tanks, etc. Environmental resilience can be ranked from high to low by several grades: high, increased, medium, and low. Resilience in this case is being defined as the ability of the fish population to survive a spill without human intervention. We have defined the resilience using population density - the lower the density of fish, the higher the ability of the population to withstand the impact of an oil spill. Based on the above, environmental resilience for rare and economically valuable fish is as follows:

Ob River main riverbed:

Sturgeon family (sturgeon, sterlet):

Early January/early April - high resilience (sturgeon is not present in Ob due to high mortality effects);

Early April/June - increased resilience (sturgeon is not yet present in Ob, sterlet's presence is likely);

July/October - low resilience (spawning migration of sturgeon begins in the river with peak levels in September; reverse post-spawning migration downstream of last-year spawning sturgeon begins; flow migration of sturgeon offspring begins);

November/early January - medium resilience (spawning migration of sturgeon is complete; flow migration of spawning species and offspring continues).

Whitefish family (white salmon, muksun, peled, and whitefish):

Early January/early April - high resilience (whitefish species are not present in Ob due to high mortality effects);

Early April/June - increased resilience (flow migration of last-year spawning species and

offspring);
July/October - low resilience (spawning migration of white salmon, muksun, peled, and whitefish species begins in the river with peak levels in September; reverse post-spawning migration downstream of last-year spawning whitefish species continues; flow migration of sturgeon offspring is complete);
November/early January - increased resilience (spawning migration and flow migration of mature species and offspring is almost complete).

Economically valuable fish (ide, dace, roach, pike, and perch)
Early January/early April - high resilience (fish is not present in Ob due to high mortality effects);
Early April/June - increased resilience (migration from wintering grounds to spawning grounds);
June/mid-July - increased resilience (limited number of economically valuable fish remains in the riverbed);
July/October - low resilience (the majority of fish migrate to the main riverbed since the level of water decreases; the catch averages 187.3 kg);
November/early January - medium resilience (wintering migration is almost complete, fish leaves the main riverbed for wintering grounds).

Bolshoy Salym river:
Sturgeon family (sturgeon, sterlet):
Quality is similar to the previous area, quantity - the share of sturgeon family species in Bolshoy Salym is 30% while in the area of Ob River main riverbed - 70%).
Whitefish family (white salmon, muksun, peled, and whitefish):
Quality is similar to the Ob main riverbed, quantity - the share of sturgeon family species in Bolshoy Salym is 30% while in the area of Ob River main riverbed - 70%).
Economically valuable fish (ide, dace, roach, pike, and perch) - similar to the Ob main riverbed.

Yelykova river:

Sturgeon family (sturgeon, sterlet):

high resilience (sturgeon family species are absent throughout the year);

Whitefish family (white salmon, muksun, peled, and whitefish):

May - increased resilience (only peled of the whitefish family is present in the area with a relative share of 0.1% of all fish species present in the river);

June/October - increased resilience (only peled of the whitefish family is present in the area with a relative share of 1.5% of all fish species present in the river);

October/May - high resilience (whitefish family species are absent).

Economically valuable fish (ide, dace, roach, pike, and perch):

Early January/early April - medium resilience (potentially favorable wintering site in the Yelykova river's quarry);

Early April/June - low resilience (spawning and offspring development grounds for the majority of economically valuable fish. The ratio of fish quantity per species (in percent) of dace, ide, roach, pike, and perch is 65.9/10.0/15.4/3.0/0.5);

June/mid-July - medium resilience (a significant part of mature fish and offspring migrated to flood plain feeding grounds. Relative quantity ratio for ide, dace, roach, and perch is 1.5/74.3/11.3/1.5%);

July/October - low resilience (the majority of fish migrate to tributaries due to the beginning of water level decrease);

November/early January - medium resilience (wintering migration ends, the majority of fish migrate to its main wintering grounds).

Other tributaries of Maliy Salym:

Sturgeon family (sturgeon, sterlet):

high resilience (sturgeon family species are absent throughout the year);

Whitefish family (white salmon, muksun, peled, and whitefish):

high resilience (whitefish family species are absent throughout the year);

Economically valuable fish (ide, dace, roach, pike, and perch):

Early January/early April - high resilience (fish is not present - no favorable wintering grounds);

Early April/June - low resilience (spawning and offspring development grounds for the majority of economically valuable fish);

June/mid-July - medium resilience (a significant part of mature fish and offspring migrated to feeding grounds in the flood plain. Average concentration of offspring in the Gorodishenskaya

river estuary is 141 species/m^3, Varovaya river - 171 species/m^3, Sogrina tributary - 114 species/m^3, Goreliy Log river - 90 species/m^3, average concentration for all sites is 66 species/m^3);
July/October - low resilience (the majority of fish migrate to tributaries due to the beginning of water level decrease);
November/early January - medium resilience (wintering migration ends, the majority of fish migrate to main wintering grounds).

<u>Flood plain reservoirs:</u>
Sturgeon family (sturgeon, sterlet):
high resilience (sturgeon family species are absent throughout the year);
Whitefish family (white salmon, muksun, peled, and whitefish):
high resilience (only peled is present in the flood plain in June/July with a very low ratio of 0.05%, the share of an average catch for peled is 0.14%);
Economically valuable fish (ide, dace, roach, pike, and perch):
Early January/early April - high resilience (fish are absent due to unfavorable wintering grounds);
Early April/June - medium resilience (main flood plain tributaries could serve as spawning and offspring development grounds for a part of economically valuable fish);
June/mid-July - medium resilience (intensive feeding of majority of mature economically valuable fish and offspring. Relative ratio of fish per species (in percent) for ide, dace, roach, pike, and perch is 20.7/62.5/5.2/0.14/11.2/0.14%, average catch ratio is 47.2/18.9/3.8/29.0/0.7/0.3 %);
July/October - increased resilience (small quantity of offspring and mature fish can be observed in flood plain tributaries and sors);
November/early January - high resilience (all fish leave the flood plain).

<u>Maliy Salym river:</u>
Sturgeon family (sturgeon, sterlet):
high resilience (sturgeon family species are absent throughout the year, relative ratio of sterlet in the spring-summer season is 0.1%);

Whitefish family (white salmon, muksun, peled, and whitefish):
increased resilience (only peled is present in the flood plain in the spring-summer season with a ratio of 3.75%);

Economically valuable fish (ide, dace, roach, pike, and perch):

Early January/early April - medium resilience (potentially favorable wintering grounds);
Early April/June - low resilience (spawning migration routes, spawning and offspring development grounds for the majority of economically valuable fish);
June/mid-July - medium resilience (significant part of mature fish and offspring migrated to feeding grounds in the flood plain. Relative quantity ratio for ide, dace, roach, pike, and perch is 24.1/15.5/39.6/0.5/4.8/7.0%);
July/October - low resilience (the majority of fish migrate to main tributaries and estuaries due to the beginning of water level decrease);
November/early January - medium resilience (wintering migration ends, the majority of fish migrate to main wintering grounds).

Waterfowl Resilience

We have used the same criteria in the environmental resilience assessment for such a group of receptors as waterfowl. The sites with high concentration of waterfowl, such as nesting and feeding grounds, as well as migration stopovers, are characterized as low resilience for this group. Such areas are represented by flood plain lakes with coastal vegetation and Maliy Salym tributary and adjacent territories. High resilience area is observed at the terrace due to a high dispersal factor (high anthropogenic impact) and the fact that this area is not located in the flood plain, therefore there are practically no waterfowl species which, in turn, produces high resilience characteristics. Similar conclusions can be made in regard to the main Ob riverbed where the dispersal factor will be significant due to commercial navigation. A distinctive border (low resilience - high resilience) in the Maliy Salym tributary area is observed due to anthropogenic impact (dispersal factor), relatively distinctive flood plain borders, and high attractiveness of Maliy Salym tributary to waterfowl species. The remaining part of the flood plain is classified as a medium resilience area.

Vegetation Resilience

We have used the following data and information in our assessment of environmental resilience. Several periods in the process of oil field development could be earmarked relative to impact on the environment and consequences of such impact. Air pollution is one of the major problems of environmental security. Thus, impact of air pollutants on the environment is referred to as “pathogenic” due to its harmful effect on vegetation. Naturally, in the area of oil development, the air will be polluted, first of all, with volatile hydrocarbon particles mixed with toxins that develop during casing-head gas burn-off.

Impact of pollutants depends on concentration in the air and impact duration. Pollutants penetrate vegetation via routes (stomates) that are used in photosynthesis, respiration, and transpiration. An additional route of penetration is through root system after pollutants are deposited on the ground via atmospheric precipitation.

Toxins that penetrate vegetative tissue aggregate in chloroplasts. The change in chloroplast profiles (from oval to round), granular structure disturbance, swelling and degradation of tilecoids, and swelling of lammels occur as a result of such impact. Membrane disturbance, granulation of cytoplasm and plastid matrix, disintegration of ribosome and endoplasmic reticulum, as well as destruction of organoids are caused by high concentration of toxins. As a result, the entire cell structure is irreversibly destroyed. Various species of vegetation have different reaction to pollution. Moreover, each reaction could be strengthened or weakened by geophysical factors. In our case, vegetation that has phylogenetically adapted to such conditions has less resistance towards gases due to the presence of acid and moist soils in the forest-tundra area. Environmental and geographic genesis of species and the conditions of mineral in-take by soils determine the volume of cation and anion exchange which increases gas resilience in vegetation. Thus, coniferous pine needles of trees that grow on chalk soils have gas resistance levels 2-3 times higher than the trees growing on sandy soils.

Lichen are especially sensitive to air pollution because they lack gas and water-proof cuticles that are characteristic of blooming and coniferous plants, thus the gas exchange with the atmosphere is conducted on the entire surface. The majority of toxic gases are easily soluble in rain water which lichens absorb via their entire surface and accumulate toxic compounds. As a result, lichen become sterile. Lichens have disappeared almost entirely in the suburbs of large cities due to extreme sensitivity to air pollution.

There’s no consensus on relative gas resilience of coniferous and deciduous tree species, although the majority of scientists tend to believe that coniferous tree species have less gas resilience due to the ability to absorb toxins during the fall-winter-spring season when air temperatures are -5 - -6°C. The most critical period for coniferous and deciduous tree species is the mid-summer season that can vary, for example, from 10 days for larch and 30 days and more for warty birch under the conditions of high air pollution. It is customary to consider tree species to have high resilience to gases if damage to foliage ranges from 0 to 20%, medium resilience - 21-50%, low resilience - more than 50%. Crown cover plays a major role in localizing gas pollution, while plants in lower layers are less important along with tree branches and stems. Forest stands with higher density also have greater resilience to gases. Although, our data on the research conducted in the area adjacent to an oil processing plant proves that pine and larch forest stands retain an acceptable growth rate and don't show signs of desiccation despite negative impact generated by air pollution in the oil processing plant area by such toxins as hydrocarbons with sulfur ingredients. Based on such data and considering the fact that the oil processing plant represents a greater risk than oil development sites relative to the entire complex of negative factors, it is conceivable to reach an "interim conclusion" that it will be possible to preserve viability of the forest community in Priobskoye oil field at a relatively high level in the near future. Based on the aforementioned factors, it is possible to conclude that forests in the research area are characterized by relatively high resilience levels.

APPENDIX C. DESCRIPTION OF SITE 3 GIS LAYERS

Table 6. 1:25,000 Scale GIS of Site 3

4.6.4.3 Export	**Attribute Name**	**4.6.4.3 Description**
	SPOT Derived Coverages	**4.6.4.3**
stlmnts3		**4.6.4.3** Settlements
road3.e00		Roads (lower 2/3)
expsite3.e00		Exploratory sites
	4.6.4.3 Russian Coverages	
density.e00	density_m	Waterfowl population density during migration to the area and prior to departure from the area, birds per km^2
	density_j	Density of waterfowl population in the summer, birds per km^2
birds.e00	birds	Waterfowl nesting and feeding grounds
s6.e00		Unpaved roads (upper 1/3)
s11.e00		Sites prepared for drilling
dem.e00	height	Landscape isolines
polut.e00		Pollution of surface waters
polut_s.e00		Pollution
	4.6.4.3 Combined Coverages	
s_all.e00	field	Combined vegetation
river.e00		Combined rivers (main riverbeds)
lake.e00		Combined lakes
streams.e00		Combined streams
dnc.e00		Pump stations (re-registered layer)
kust.e00		Oil well clusters (re-registered layer)
lep.e00		Powerlines (reregistered layer)
pipeline.e00		Pipelines – Russian option (re-registered layer)
prist.e00		Dock (re-registered layer)
road.e00		Proposed road

Natural conditions in the test site area

The test site is located in the northern section of Priobskoye oil field with the following coordinates: 61°16' - 61°24' N. latitude, 70°19' - 70°36' E. longitude.

Landscape conditions in the test site area in general are similar to landscape conditions in the test site 1. All types of landscape conditions are represented in the test site area that are characteristic of the Mid-Ob region. The main feature that forms local landscape is the Ob River. The Ob's riverbed meanders through large distances and forms numerous small lakes and streams.

Several distinctive sections are represented in the flood plain: frequently flooded, occasionally flooded, and rarely flooded areas. The flood plain is covered by meadow and marsh grass vegetation with sparse forests growing on top of elevated areas. The flood plain is speckled with meandering streams, sors and flood plain marshes. The landscape features include terraces, sand spits, and bank arches, as well as "ridges" - erosion remnants of river terraces. Flood plain lakes are generally small - from several dozen meters to several kilometers in diameter and usually up to 5 meters deep.

The terrace within the test site boundaries is a marshy and relatively sloping area with dense forest vegetation. A large number of small and shallow lakes are observed in the terrace area. Terrace boundaries are parallel to the Ob River's main riverbed with elevation over the Ob River water level of 15 meters. Highland flood plain is also observed in the test site area located along the Ob River's right bank. Its surface is relatively flat and speckled with numerous small marshes and lakes. Low mounds and spiral depressions are also common.

The rivers in the test site area are characterized with relatively slow current due to insignificant angle of elevation in landscape features. As mentioned earlier, the Ob River meanders sharply, thus creating numerous sors and lakes. It is necessary to note the existence of two large rivers in the test site area - Labytvor channel and Balinskaya river - that are of interest to researchers due to the fact that the areas of habitat for numerous fish and waterfowl species are adjacent to these rivers. Labytvor channel flows through the middle section of the test site area in parallel to the Ob River's main riverbed and stretches for 10 to 12 kilometers in the research area. Balinskaya river runs through the central section of the test site 3 in sub-meridian direction for 15 to 17 kilometers in the research area. Tributaries are supplied with water from local high-ground waters and surface water run-offs. Water level in the Ob River rises significantly during spring flood season due to discharge of water from melted snow and ice. Water level in the Ob River increases by 5 to 7 meters over its normal readings during spring floods in average years, while during the years characterized by higher floods the water level can increase by more than 10 meters, thus flooding the most of flood plain area. All large and small water reservoirs are also flooded and the significant increase in water volume is also caused by heavy rainfall that is common in this area in the spring. It is necessary to stress the creation of small lakes (sors) in the flood plain during this season. Sors are first flooded in the beginning of flooding in late April - early May and remain filled with water until late July - early August. Usually, sors are connected with the rivers through narrow flood channels. Sors often serve as spawning grounds for fish in the spring. Late October marks the beginning of water freezing in the research area. Ice blocks water channels resulting in the increase in water levels. Decrease in oxygen concentration levels is observed due to ice formation processes. Climate conditions in the research area are entirely similar to that described in the Site 1 description.

Site 3 is of interest to researchers due to the location of waterfowl habitat. The area is covered with a significant number of lakes of various size and different shoreline features - from flood plain lakes that are flooded during flood season to forest lakes that have very distinctive banks. According to observations, the largest populations of waterfowl have been observed along Balinskaya river and Labytvor channel. In addition, waterfowl are attracted to highly productive lakes with plentiful fish supplies and no annual sedimentation as well as side channels of the Ob River where underwater vegetation serves as an abundant food source.

A waterfowl population density map has been developed based on existing data as well as analytical expert assessments using topological maps and space-based imagery (Figure 25). Some clarification of the lower left section of the density map is in order. Several lakes that are attractive to waterfowl are located in this section, although such lakes are not the primary habitat areas due to their proximity to settlements (for example, Selyairovo).

The ecological resilience map for Site 3 has a much more complicated structure and is of greater interest than the similar map for the test site 1 due to the following reasons:

Local topology is more diversified compared to the Site 1.

1. The site could be classified as presently unaffected by anthropogenic impact.

There is a large number of channels, rivers, lakes, and streams that attract waterfowl. Therefore, the total population of waterfowl in the Site 3 is much greater than in the Site 1. If we compare ecological resilience in these two sites, than the total ecological resilience in the Site 3 is much lower than in the Site 1. We have applied similar overall methodology to the development of waterfowl's ecological resilience maps. The nature of anthropogenic impact is different from that in the test site 1 where such impact is represented by oil production sites, whereas in the test site 3 impact is provided by settlements (oil development of Site 3 is relatively low).

Infrastructure

The existing infrastructure sites include Selyairovo settlement on the Ob's right bank, the dock, and three oil well clusters under construction where sand pour-off is presently conducted. According to our data, road construction is presently underway on the Ob's right bank. The road is planned to connect the dock and Selyairovo settlement. Those infrastructure sites are largely located in the upper flood plain area on the Ob's right bank. According to our data, construction of several dozen oil well clusters that will be connected by pipelines is planned in the research area along with several pump stations and at least one central oil collection unit. The construction of such sites will most likely be accompanied by construction of roads, powerlines, pipelines, and housing units for personnel with appropriate infrastructure development.

Figure 25