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Research and Special Programs Administration
Office of Pipeline Safety

Technical Task Order Number 3
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Integrity Management Program

Surface Hydrology Analysis

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Final

This report is intended to serve as a technical resource for OPS and State pipeline safety inspectors evaluating operators' integrity management (IM) programs. Inspectors consider information from a number of sources in determining the adequacy of each IM program. Development of this report was funded via a Congressional appropriation specifically designated for implementation of IM oversight. This and other similar reports are separate and distinct from the work products associated with and funded via OPS's R&D Program.

Submitted by:

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March 13, 2003

Executive Summary

Federal regulation 49 CFR 195.452 requires operators of hazardous liquid pipelines to identify all pipeline segments that could affect High Consequence Areas (HCAs) in the event of an accidental release. Inspectors for the Office of Pipeline Safety (OPS) are currently guided in their review of operator submittals by the January 2003 Comprehensive Integrity Management Inspection Protocols. OPS inspectors reviewing operator submittals with respect to the surface water transport of spilled hazardous liquids are guided primarily by Inspection Protocol #1.07 which reads:

> *Does the operator's process include a technically adequate analysis of water transport of liquids to determine the extent of commodity spread and its effects on HCAs?*
>
> *Verify that the operator produced a water transport analysis (if applicable) that is technically adequate and consistent with its program requirements.*

In order to assist OPS inspectors in addressing the issues raised in Inspection Protocol #1.07, Michael Baker Jr., Inc. developed an approach and checklist for inspectors to use in determining operator compliance in their analyses of the surface water transport of spilled liquids. Completion of the work involved the performance of a number of subtasks.

Research was conducted in order to determine where specific flood recurrence intervals are called out in Federal, State, and national organizational codes, standards, and design guidelines. The results of the research, with particular emphasis on low probability floods mentioned in the various sources, were summarized and also incorporated into the performance of other subtasks.

A summary was produced of specific risk factors that should be considered in the analysis of a product release near a stream channel or floodplain. Risk factors were grouped and individual risk factors were discussed to explain how they could affect the development of a surface water transport analysis.

Risk scenario combinations were developed. These combinations of failure type (a combination of failure mode and cause), and surface hydrological and seasonal conditions are those that should be evaluated in operators' surface water transport analyses. The appropriate risk scenario combinations to use will vary from operator to operator, and will be based on the pipeline's age, configuration, and layout; the proximity of the pipeline to stream channels and floodplains; local topography; and regional hydrologic and climatic conditions.

An approach was developed that OPS inspectors can use in determining compliance in operator's analyses of surface water transport of spilled liquids. The approach is intended to provide inspectors with explanatory background information and descriptions of analysis steps that an operator should be using in the performance of a technically adequate analysis of surface water spill transport.

The approach is presented as a flow chart and supplemental detailed plates, and is broken down into two general parts - the establishment of the basic analysis inputs and components, and the analysis of results and impacts. In establishing the basics, the appropriate risk scenario combinations are first identified (Step 1) and then, based on the combinations identified, the appropriate spill transport methodologies and spill situations (physical locations of spills) are defined (Step 2).

The analyzing of results and impacts begins with an initial screening to establish the zone of influence of the spill (Step 3). This screening uses preliminary estimates of discharge, water level, and velocity to determine whether there are concerns that HCAs identified in the operator's segmentation analysis could be affected by a postulated spill. If an HCA is determined to be outside the zone of influence of the postulated spill (for example, if the HCA is determined to be located too far downstream to be affected by the spill, or is determined to be located outside of a stream's floodplain), then the HCA can be dropped from further consideration. If the screening determines that an HCA could be affected by a postulated spill, however, then further, more detailed hydrologic and hydraulic analyses are required for either open water (Step 4A) or ice-affected (Step 4B) conditions. Analytical tools and computation techniques for detailed surface water transport analyses are also provided. Based on the results of the detailed analyses, if an HCA is identified as not being affected by the postulated spill, it is removed from further consideration. If a detailed analysis determines that an HCA could be affected by a postulated spill, however, then assessment and implementation of mitigative measures would be required, with periodic review and updating of these measures, as necessary.

It is not anticipated that any surface water transport analyses will need to be performed by OPS inspectors. The approach is provided so that inspectors will understand the steps and analysis techniques that an operator should be using in the performance of technically adequate surface water transport analyses.

Based on the approach described above, a one-page inspector's checklist was developed that guides an OPS inspector through an evaluation of an operator's surface water transport analysis submittal. The checklist allows an inspector that is familiar with the approach described in this report to systematically go through an operator's submittal and check off whether or not an adequate analysis has been performed. It is recommended that operators be given access to this report and the inspector's checklist so that they understand what an OPS inspector will be looking for in their submittal review.

Two example scenarios - one rural and one urban - were developed using actual locations and associated mapping, climatic, and hydrologic data, and hypothetical pipelines and associated facilities. Example surface water transport analyses were developed. Discussions are provided to show how OPS inspectors might use the developed approach and checklist when evaluating such analyses.

Note to Readers

Readers of this report are encouraged to initially read the document in its electronic format using the Acrobat Reader computer program. There are links embedded within the report that allow the reader to navigate between the report and Internet web sites from which relevant report information was taken. There are also links within the Surface Water Analysis Approach flow chart and detailed plates in Section 5 that allow readers to quickly navigate between individual plates, and also between the detailed plates and report appendices.

When printing paper copies, Figures 1 and 2 at the end of Section 6 are most easily read when printed in color on 11”x17” sheets.

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1. Introduction

Federal regulation 49 CFR 195.452 requires operators of hazardous liquid pipelines to identify all pipeline segments that could affect High Consequence Areas (HCAs) in the event of an accidental release. Inspectors for the Office of Pipeline Safety (OPS), under the U.S. Department of Transportation's Research and Special Programs Administration, are currently guided in their review of operator submittals by the January 2003 Comprehensive Integrity Management Inspection Protocols. OPS inspectors reviewing operator submittals with respect to the surface water transport of spilled hazardous liquids are guided primarily by Inspection Protocol #1.07, Segment Identification - Water Transport Analysis. Inspection Protocol #1.07 reads:

> *Does the operator's process include a technically adequate analysis of water transport of liquids to determine the extent of commodity spread and its effects on HCAs?*
>
> *Verify that the operator produced a water transport analysis (if applicable) that is technically adequate and consistent with its program requirements.*

In order to assist OPS inspectors in addressing the issues raised in Inspection Protocol #1.07, Michael Baker Jr., Inc. (Baker) has developed an approach and checklist for inspectors to use in determining operator compliance in their analyses of the surface water transport of spilled liquids. (Note: At the start of this project, the most current version of the Comprehensive Integrity Management Inspection Protocols was dated September 2002. Under that version, Protocol #1.10 guided inspectors in the determination of operator compliance in their analyses of surface water transport. Although the wording varies slightly between the January 2003 Protocol #1.07 and the September 2002 Protocol #1.10, the intent of the two protocols is the same.)

A draft report outline was submitted to the OPS on January 03, 2003. In a conference call on January 08, the OPS gave their approval of the presented approach, and provided comments and suggestions on the format and content of a draft report. Those comments and suggestions were incorporated into a draft report that was submitted to the OPS on February 14. In a conference call on February 19, review comments and suggestions on the draft report were received from the OPS. Those comments and suggestions have been incorporated into this final report. The major differences between the draft and final reports consist of (1) the conversion of the draft report's Supplemental Checklist into an explanatory flow chart for the surface water transport analysis approach, and (2) the development of a one-page inspector's checklist based on the presented approach.

1.1 Scope of Work

This report has been developed in accordance with the Scope of Work Narrative presented in Baker's proposal responding to the OPS Request for Proposals for Technical Task Order (TTO) No. 3, entitled "Surface Hydrology Analysis." The Scope of Work Narrative presented in Baker's TTO No. 3 proposal covered five subtasks. These subtasks are listed below:

Subtask 01 - Risk-based Approach Research: Baker will research available data relating to risk-based approaches in established regulatory codes and standards. The emphasis will be on U.S. codes and standards, although reference to foreign codes and standards will be examined.

Subtask 02 - Risk Factor Assessment: Baker will conduct a survey of specific risk factors to be considered in the analysis of a product release near a watercourse or wetlands area and discuss how these risk factors could affect the development of a risk scenario that should be analyzed further. Risk factors will be grouped, to the extent possible, and general risk scenario combinations of product release and surface hydrological conditions (e.g., product release during a 100-year return flood) that would require separate analyses and/or analytical approaches will be identified.

Subtask 03 - Example Scenario Development: Based upon the information gathered during Subtasks 01 and 02, Baker will develop two example scenarios and prepare an example operator evaluation submittal, which explains the scenarios to be evaluated, their basis in risk analysis, and the potential consequences that are especially relevant to each scenario.

Subtask 04 - Hydrologic Evaluation Research: Baker will survey and evaluate the analytical approaches for assessing the effects of release scenarios. We will develop a matrix that guides the evaluation of a scenario to an appropriate analysis based on the near topology, ecology, product characteristics, climatic conditions and surface hydrological factors.

Subtask 05 - Position Paper: Baker will develop a position paper on the combination of product release scenarios and surface hydrological conditions that should be evaluated to find the consequences of a release near a watercourse or wetlands area.

1.2 Work Task Approach

In order to complete the work outlined in the Scope of Work Narrative, the approaches presented below were developed for each subtask. It should be noted that the subtask approaches are not presented in numerical order. Instead, they are presented in the order in which they were logically addressed and incorporated into the report.

<u>Subtask 01 - Risk-based Approach Research:</u> The main focus of this subtask was to determine where and when specific flood recurrence intervals are called out in U.S. Federal, State, and national organizational codes, standards, and design guidelines for the purposes of design, analysis, risk assessment, or the determination of flood insurance rates. Information identified during this background research effort is summarized in Section 2. The results of the research, with particular emphasis on low probability floods mentioned in the various codes, standards, and guidelines, are also incorporated into the performance of other subtasks described below.

Subtask 02 - Risk Factor Assessment: A summary was produced of specific risk factors that should be considered in the analysis of a product release near a stream channel or floodplain. Risk factors are grouped and individual risk factors are discussed to explain how they could affect the development of a surface water transport analysis. The risk factor discussion is presented in Section 3.

Risk scenario combinations were developed. These combinations of failure type, and surface hydrological and seasonal conditions are those that should be evaluated in operators' surface water transport analyses. The appropriate risk scenario combinations to use will vary from operator to operator, and will be based on the pipeline's age, configuration, and layout; the proximity of the pipeline to stream channels and floodplains; local topography; and regional hydrologic and climatic conditions. Risk scenario combinations are discussed and presented in Section 4.

Subtask 04 - Hydrologic Evaluation Research: An approach was developed that OPS inspectors can use in determining compliance in operator's analyses of the surface water transport of spilled liquids. The approach is intended to provide inspectors with explanatory background information and descriptions of analysis steps that an operator should be using in the performance of a technically adequate analysis of surface water spill transport. Based on this approach, a one-page inspector's checklist was developed that guides an OPS inspector through an evaluation of an operator's surface water transport analysis submittal. The checklist allows an inspector that is familiar with the approach described in this report to systematically go through an operator's submittal and check off whether or not an adequate analysis has been performed. The surface hydrology analysis approach and inspector's checklist are presented in Section 5.

Subtask 03 - Example Scenario Development: Based upon the work performed on Subtasks 01, 02, and 04, two example scenarios for a surface water transport analysis were developed. The example scenarios - one rural and one urban - were developed using actual locations and associated mapping, climatic, and hydrologic data. The product lines included in the scenarios, however, are purely hypothetical. These example scenarios underscore the use of the surface hydrology analysis approach developed under Subtask 04 for OPS inspectors to use when evaluating an operator's surface water transport analysis. The example scenarios are described and presented in Section 6.

Subtask 05 - Position Paper: Sections 2 through 4 of this report serve to satisfy the work requirements of Subtask 05 - a position paper on the combinations of product release scenarios and surface hydrological conditions that should be evaluated by an operator in the performance of surface water transport analyses.

2. Risk-Based Approach Research

2.1 Research Overview and Sources

Risk-based approach research was conducted in order to determine where and when specific flood recurrence intervals are called out for the purposes of design, analysis, risk assessment, or the determination of flood insurance rates in various Federal, State, and national organizational codes, standards, and design guidelines. The research results, with particular emphasis on high magnitude, low probability floods mentioned in the various sources, are summarized in the following sections.

The following is a list of the agencies and organizations that have been surveyed. Applicable text and explanations are provided for relevant agencies in the succeeding sections of this chapter:

- Federal Emergency Management Agency (FEMA), http://www.fema.gov/
- United States Army Corps of Engineers (USACE), http://www.usace.army.mil/
- Federal Highway Administration (FHWA), http://www.fhwa.dot.gov/
- Federal Energy Regulatory Commission (FERC), http://www.ferc.fed.us/
- American Society of Civil Engineers (ASCE), http://www.asce.org/
- Natural Resources Conservation Service (NRCS), http://www.nrcs.usda.gov/
- National Water and Climatic Center, http://www.wcc.nrcs.usda.gov/wcc.html
- Ohio Department of Natural Resources (ODNR), http://www.dnr.state.oh.us/water/
- Ohio Water Development Authority (OWDA), http://www.owda.org/
- United States Bureau of Reclamation (USBR), http://www.usbr.gov/main/
- United States Geological Survey (USGS), http://www.usgs.gov/
- Association of State Dam Safety Officials (ASDSO), http://www.damsafety.org/.
- Transportation Association of Canada (TAC), http://www.tac-atc.ca/
- National Inventory of Dams (NID), http://crunch.tec.army.mil/nid/webpages/nid.cfm

2.2 Research Results

Research was conducted using the Alaska Resources Library and Information Services, government web sites, Internet search engines, and design reference libraries maintained by the report authors. The sections below summarize specific sources and present a brief discussion of the information found.

2.2.1 Building Codes

A number of building codes were examined to determine if specific flood recurrence intervals are called out for the purposes of design, analysis, or risk assessment. The various codes surveyed are listed below.

- International Building Code, published by the International Code Council (ICC)
- International Residential Code for One- and Two-Family Dwellings, published by ICC
- Uniform Building Code, published by the International Conference of Building Officials
- The BOCA National Building Code, published by Building Officials & Code Administrators International (BOCA)
- Standard Building Code, published by the Southern Building Code Congress International
- International One- and Two-Family Dwelling Code, published by the Council of American Building Officials

No relevant information was discovered in the above-listed codes that would assist with the analysis of surface water transport.

2.2.2 National Flood Insurance Program

In 1968, Congress passed the National Flood Insurance Act. The National Flood Insurance Program (NFIP) created by this act is a voluntary program that aims to reduce the loss of life and the damage caused by flooding, to help victims recover from floods, and to promote an equitable distribution of costs among those who are protected by flood insurance and the general public. The NFIP operates as a partnership between Federal, State, and local governmental agencies, and is administered by FEMA.

Flood hazard information for each community is presented in a Flood Insurance Rate Map (FIRM) and Flood Insurance Study (FIS). The boundary of Special Flood Hazard Areas (SFHA) is defined as the area subject to inundation by the flood that has a 1-percent probability of being equaled or exceeded in a given year (100-year flood). For areas affected by coastal flooding, FEMA analyzes the 100-year stillwater elevations, the maximum 100-year wave heights and, in certain areas, the maximum 100-year wave runup associated with the stillwater elevations in order to determine the appropriate base flood elevation (BFE) for inclusion in the FIRM.

The magnitude and severity of flood hazards are grouped into flood insurance zones for inclusion on the FIRMs. A brief description of the zones is as follows:

- **Zone A:** 100-year floodplain determined by approximate methods
- **Zone AE and A1-A30:** 100-year floodplains determined in the FIS by detailed methods
- **Zone AH:** 100-year shallow flooding with a constant water-surface elevation (areas of ponding) with average depths of 1–3 feet; BFEs derived from detailed hydraulic analyses
- **Zone AO:** 100-year shallow flooding (sheet flow on sloping terrain) with average depths of 1–3 feet; BFEs from detailed hydraulic analyses
- **Zone AR:** areas protected from flood hazards by flood control structures
- **Zone A99:** areas of the 100-year floodplain that will be protected by a Federal flood protection system where construction has reached a specified statutory milestone
- **Zone D:** possible, but undetermined flood hazards exist; no analysis has been conducted

- **Zone V:** 100-year coastal floodplain with additional hazards associated with storm waves; approximate hydraulic analyses of BFEs performed
- **Zone VE:** 100-year coastal floodplain with additional hazards associated with storm waves; detailed hydraulic analyses of BFEs performed
- **Zones B, C, and X:** correspond to areas outside the 100-year floodplains, areas of 100-year sheet flow flooding where average depths are less than 1 foot, areas of 100-year stream flooding where contributing drainage area is less than 1 square mile, or areas protected from the 100-year flood by levees

2.2.3 Association of State Dam Safety Officials

The Association of State Dam Safety Officials maintains an internet-based information clearinghouse for further information regarding specific hydrologic, hydraulic, structural, and geotechnical design criteria on a state-by-state basis. A cursory review did not reveal any information regarding specific flood recurrence intervals.

2.2.4 United States Army Corps of Engineers

Congress has authorized the U.S. Army Corps of Engineers (USACE) to maintain and periodically publish an updated National Inventory of Dams (NID) located in the United States. A total of approximately 77,000 dams have information presented in the NID. Also examined were USACE Civil Specifications and a USACE manual for the design of flood control channels. A cursory review of these various materials did not reveal any information regarding specific flood recurrence intervals.

2.2.5 Federal Highway Administration

A review of several Federal Highway Administration design manuals and technical publications identified a range of design flood recurrence intervals, the most common of which is the 100-year flood event. Identified flood recurrence intervals range from the 10- to 50-year floods for the design of riprap revetments. The 100-year flood event is commonly applied with respect to culvert design and evaluating scour at bridges.

2.2.6 United States Geological Survey

The United States Geological Survey has developed various methodologies for evaluating scour at bridge locations. These methods begin with the determination and consideration of the 100-year flood. In certain instances, the USGS uses the more extreme 500-year flood event.

2.2.7 Canadian Design Criteria for River Crossings

Canadian provinces are responsible for establishing their own pipeline design criteria. In Alberta, where more than 90% of Canadian pipelines are located, the 50-year flood is used for the design of gas pipelines and the 100-year flood is used for the design of oil and hazardous liquid pipelines. British Columbia applies the 200-year flood for the design of all pipelines. Northern Canadian provinces apply a percentage of the probable maximum precipitation to arrive at a design flood event.

2.2.8 Alaska Department of Fish and Game

The Alaska Department of Fish and Game (ADF&G) identifies design recurrence intervals for permanent stream structures and river rehabilitation projects. The mean annual flow is identified by the ADF&G for fish passage; the 2-year flood for the design of bankfull channel structures; the 25-year flood for defining the lowest terrace level; and the 100-year flood to define the upper limit of the inactive floodplain.

2.3 Conclusions

Risk-based approach research was conducted in order to determine where and when specific flood recurrence intervals are called out in various Federal, State, and national organizational codes, standards, and design guidelines. Citations were discovered ranging from the 2-year flood to the 500-year flood for the purposes of design, analysis, risk assessment, or the determination of flood insurance rates. The most commonly identified flood recurrence interval for consideration in the design, protection, or analysis of critical facilities was the 100-year flood.

3. Risk Factor Assessment

A survey was conducted in order to summarize risk factors that should be considered in the surface water transport analysis of a product release from a pipeline. This research was aided by previous work provided by the OPS for the effects of spills of specific liquid products within inland waterways and their relative risk rankings (Kadner, 2002; Appendix A). The summarized risk factors include both hydrologic and non-hydrologic types. Each identified risk factor is discussed to explain how it could affect the performance of a surface water transport analysis.

The risk factor survey was facilitated by extensive use of the Alaska Resources Library and Information System, various government web sites, Internet search engines, and prior project experience by the report authors.

3.1 Risk Factors Described in Pipeline Integrity Management Regulation 49 CFR 195.452

Federal regulation 49 CFR 195.452 describes the risk factors that must be considered by an operator for establishing an assessment schedule. These risk factors include, but are not limited to, the following:

- Results of previous integrity assessments, defect type and size that the assessment method can detect, and defect growth rate
- Pipe size, material, manufacturing information, coating type and condition, and seam type
- Leak history, repair history, and cathodic protection history
- Product transported
- Operating stress level
- Existing or projected activities in the area
- Local environmental factors that could affect the pipeline (e.g., corrosivity of soil, subsidence, or climatic factors)
- Geotechnical hazards
- Physical support of the segment such as by a cable suspension bridge

All of the risk factors listed above need to be considered in an operator's segmentation analysis, prior to the performance of either an analysis of surface water transport of spilled liquids, or a zone of influence ("could affect") analysis. The above-listed risk factors will determine the causes of potential spills, where and when potential spills might be expected to occur, spill volumes, the physical and chemical characteristics of the spilled product, and the modes of surface water transport of the spill.

When performing analyses of the surface water transport of spilled liquids, the risk factors of greatest importance include those relating to the mode and cause of the pipeline failure, the type of product transported, and local environmental factors. The local environmental risk factors of interest in this study are primarily hydrologic in nature.

3.2 Pipeline Failure Mode Risk Factors

Risk factors that govern the mode of pipeline failure will determine the amount of product that could potentially be spilled and, therefore, the volume of spilled liquids assumed in a surface water transport analysis. The two failure mode endpoints are:

1. A guillotine break (a complete rupture of a pipe resulting in a total throughput release)

2. A minor leak that would be difficult, if not impossible to detect with an operator's Supervisory Control and Data Acquisition (SCADA) leak detection system.

The guillotine break mode of failure will result in the largest volume of product spilled in the shortest amount of time. The volume released will be determined by the limitations of the operator's SCADA leak detection system, shutdown response time, and the volume of product remaining within the pipeline between valves adjacent to the leak after the pipeline shutdown has been implemented. For the purposes of surface water transport analyses, this mode of break will produce the largest concentrations of spilled liquids entering and being transported by a stream.

The minor leak mode of failure will have different ramifications for surface water transport. While concentrations entering surface waters will be much lower than for a guillotine break of the same pipe, significant volumes of spilled liquids can be released before a minor leak is detected. If the leak continues unabated for a significant period of time, large spill volumes could result. The volume released will be determined by the length of time between the start of the leak and the operator's shutdown response time, and the volume of product remaining within the pipeline between valves adjacent to the leak after the pipeline shutdown has been implemented. For the purposes of surface water transport analyses, this mode of break will produce the lowest concentrations of spilled liquids entering and being transported by a stream for a given pipeline. More importantly, however, the minor leak mode of break could potentially have the longest travel distances depending on the length of time that passes prior to leak detection and facility shutdown.

Between these two failure mode endpoints, combinations of generally lower spill concentrations and shorter surface water transport distances would be expected.

3.3 Pipeline Failure Cause Risk Factors

For the purposes of surface water transport analyses, risk factors relating to pipeline failure causes are broken down into two groups - hydrologic and non-hydrologic. These two groups of causative risk factors will directly influence the location of a pipeline failure.

Hydrologic pipeline failure causes include scour and bank migration. Scour involves sediment transport and erosion processes that cause streambed materials to be removed from the bed and banks of streams, and from around the base of structures built within stream channels. Such structures would include bridge piers and abutments, docks, and erosion control structures. Scour is basically a vertical erosion process resulting in the lowering of the streambed. Scour presents a risk to pipeline integrity by its potential to expose buried pipeline crossings, thus making them vulnerable to rupture from hydraulic forces, forces placed on the pipe by entrained debris such as trees, or damage by coarse sediment carried along the bottom of the streambed. Scour can also present a risk to pipeline integrity by undermining the foundations of pipeline bridges.

Bank migration involves the lateral movement of the bank of a stream channel. Bank migration is an ongoing natural process in meandering streams but is also common in braided channel systems where rapid changes in discharge, sediment load, and sediment-carrying capacity result in frequent channel changes. Bank migration presents a risk to pipeline integrity by its potential to expose pipeline structures located in the floodplain to forces that are associated with the active channel of a stream. In this situation, shallow-buried pipelines can be exposed and damaged, and the support members of aboveground pipelines can be undermined. Bank migration can also contribute to the undermining of the foundations of pipeline bridges.

Both scour and bank migration are naturally occurring stream processes. The introduction of man-made structures into the channel of a stream, however, can increase the rate and intensity of these processes as a result of flow impingement.

Because scour and bank migration are processes that occur in active stream channels, pipeline failures resulting from these hydrologic causes will be restricted to locations in or near the active stream channel.

Non-hydrologic pipeline failure causes include corrosion, mechanical and third party damage, earthquakes, landslides, weld/seam failures, etc. Except for certain site specific non-hydrologic failure causes such as landslides, failures resulting from these causes could be expected to occur almost anywhere along the length of a pipeline.

The location of failures resulting from non-hydrologic causes will have a direct effect on the performance of surface water transport analyses. Failures located within or near the active channel could be subject to transport by normal and low volume stream flows as well as flood flows. Failures located within the floodplain of a stream will only be subject to surface water transport during flood flows. For instance, a spill located along the margin of the 100-year floodplain of a stream (the area that would be inundated by a 100-year flood) would likely only be subject to surface water transport during 100-year flood conditions. For spills located in upland areas (outside the boundaries of a stream's floodplain), surface water transport would only occur if overland transport first carried the spilled liquids to the floodplain or active channel of the stream.

3.4 Hydrologic Conditions Risk Factors

Risk factors relating to hydrologic conditions will have a direct influence on the surface water transport analysis of spilled liquids. For a given stream, spills transported during normal or low flow periods will be characterized by higher concentrations because of the lower water volumes, and the spread of spills will be restricted to the active channel of the stream. Transport rates will be relatively low due to the lower flow velocities occurring during these conditions. Channel characteristics such as channel pattern, downstream changes in channel pattern, influent or effluent flow regimes, and velocity variations within the channel will influence the spread of the product release.

The pathways of in-channel spilled liquid transport can be expected to differ between channels with different patterns. For example, transport of a spill will be different in a single meandering channel versus transport in a braided stream. Further, channel patterns can be expected to change downstream. For example, a high gradient mountain stream with a braided channel may change to a split channel pattern passing through foothills along the mountain front, and then change again to a single meandering channel as the stream enters the lowlands. These downstream channel pattern changes can be expected to affect spilled liquid transport pathways.

Gaining (effluent) and losing (influent) streams can be expected to behave differently with respect to the in-channel transport of spilled liquids. In gaining streams, where groundwater travels from the stream banks and bed into the stream channel, spilled liquids would be expected to travel downstream at approximately the rate of the water flowing in the channel. In a losing stream, however, spilled liquids could be transported from the flow in the channel into the subsurface of the streambed and banks as bank or channel storage. This would have implications for spilled liquid travel time, spill response, and mitigation since the stream could later change to a gaining condition, resulting in release and re-entrainment of the spilled liquid into flowing surface waters.

There will be cases where the surface water transport of spilled liquids has the greatest adverse effect on an HCA during normal or low flow conditions. Such cases might include the transport of a spilled liquid to a surface water supply intake, transport into the subsurface of a drinking water aquifer from the bed of an influent stream, or contamination of critical shore or in-stream habitat of a threatened or endangered species.

Spills transported during flood conditions will be characterized by lower concentrations because of the higher water volumes, and the extent of spill spreading could potentially cover the entire inundated portion of the floodplain. Transport rates will be relatively high near the channel due to the high flood flow velocities. Lower velocities in overbank areas will result in lower transport rates in areas further from the channel. Channel characteristics such as channel pattern, downstream changes in channel pattern, and velocity variations within the channel will have less influence on the spread of the product release during flood conditions. Instead, such factors as floodplain vegetation, valley configuration, presence or absence of a defined floodplain (such as in a canyon or concrete-lined channel), floodplain configuration, and downstream changes in floodplain and valley configurations will have a greater effect on spill transport.

Flood-inducing factors will differ by region and include snowmelt, low frequency storm systems, thunderstorms, catastrophic events (dam breaks, glacier-dammed lake outburst floods, etc.), and others.

Flow regulation by flood control structures, hydroelectric dams, etc. will result in reasonably predictable flows in downstream reaches within the regulating structure's influence. In some cases, certain reaches may not experience overbank flows.

3.5 Seasonal Conditions Risk Factors

Seasonal conditions play a major role in stream hydrology and hydraulics and, therefore, must be considered as risk factors in a surface water transport analysis of spilled liquids. Seasonal variations in flow are common in all hydrologic systems but the character of the flow variations can vary greatly among different climatic regions. Streams in arid climates may only carry significant flows in the spring from snowmelt or for short periods following storm events. Streams in moist climatic regions may carry significant flows throughout the year, and might be subject to floods during any season.

The seasonal occurrence and magnitude of high magnitude, low frequency flooding also varies greatly among different climatic regions. In temperate regions, the largest floods commonly result from persistent storm systems occurring in the summer or fall. In warm arid regions, large floods may be associated with relatively short-lived but intense thunderstorms. In cold regions, the largest floods commonly occur from snowmelt during spring breakup.

The presence of ice on streams in temperate and cold climates can have a strong effect on stream hydraulics and, consequently, on the transport and spreading of spilled liquids. A thermal ice cover formed on the surface of a stream over the course of the winter will affect stream hydraulics and spill transport. Thermal ice covers can grow to as much as seven feet thick. During the breakup of a floating ice cover, significant ice jamming effects can be produced. Ice jamming can result in the redirection of flows, rapidly rising water levels and overbank flooding, and damage to in-stream and shore facilities from impacts by ice floes. The presence of ice cover, ice jamming, and ice floes will also have major implications for spill response.

Ground-fast ice (aufeis) deposits can form in streambeds during the winter from the overflow and subsequent freezing of sheets of surface water and upwelling groundwater. Such deposits are common on the beds of braided streams in northern climates. Significant thicknesses can build up over the course of the winter, sometimes reaching thicknesses of greater than 15 feet. Such deposits can affect channel hydraulics during breakup by redirecting and constricting flows, and by increasing velocities due to lower flow resistance when water is flowing over the deposits. Redirection and constriction of flows can concentrate bank erosion in areas of the channel or floodplain that would not normally be subject to high velocity flows.

The risk factors described above have been incorporated into the risk scenario combinations presented in Section 4, and the surface water transport analysis approach and inspector's checklist presented in Section 5.

4. Risk Scenario Combinations

When performing analyses of surface water transport of spilled liquids, operators should consider certain specific risk scenario combinations. These will consist of various combinations of three critical factors that include pipeline failure types, hydrologic conditions, and seasonal conditions. The appropriate risk scenario combinations to consider will vary from operator to operator, and will be based on the pipeline's age, configuration, and layout; the proximity of the pipeline to stream channels and floodplains; local topography; and regional hydrologic and climatic conditions. Further discussions of specific risk scenario combinations and the factors considered in developing them are provided below.

4.1 Failure Types

Failure types were discussed in Section 3. They are divided into four groups based on the postulated modes and causes of failure. Failure modes are subdivided into guillotine breaks and minor leaks. Failure causes are subdivided into hydrologic and non-hydrologic causes.

4.1.1 Failure Modes

The maximum expected spill volume to be evaluated by an operator will be associated with a guillotine mode failure of a pipeline. The release should be assumed to continue unabated throughout the time needed to detect the leak and close valves to interrupt flow to the postulated release point. The minimum total spill volume to consider for a guillotine mode failure, therefore, should include the volume of product lost prior to leak detection and the closing of valves on either side of the break, and the drain-down volume to the release point between the valves. Spill volumes developed from a drain-down hydraulic analysis that considers topographic interrupt in the product release may be substituted, if available. In certain circumstances, such as when adverse effects on a downstream HCA could be extreme, it may be appropriate to require a more conservative estimate of spill volume by assuming that one or both of the adjacent valves on either side of the break do not close.

At the other end of the spectrum from a guillotine mode of failure is a release resulting from a minor leak that is difficult, if not impossible, to detect using the operator's SCADA leak detection system. For the minor leak failure mode, a slow but steady release rate could continue unabated for some time. The total volume of release, therefore, will be closely related to not only the release rate, but also the time elapsed between initial failure and the eventual interruption of flow. For a minor leak failure mode, the appropriate product release rate to evaluate would be equal to the pipeline's minimum SCADA detection limits. The time period over which the release should be assumed to occur would be the maximum realistically possible.

4.1.2 Failure Causes

Failure causes are broken down into two groups - hydrologic and non-hydrologic. Hydrologic failure causes include scour and bank migration, both of which would be expected to occur during flood conditions. Scour and bank migration could result in the exposure and failure of buried pipeline crossings, undermining of pipeline bridge foundations, undermining of vertical support members for an aboveground pipeline, etc. Failures resulting from hydrologic causes will be restricted to locations within or directly adjacent to active stream channels.

Non-hydrologic failure causes include corrosion, mechanical or third party damage, earthquakes, landslides, weld/seam failures, etc. Failures from such causes can generally be expected to occur at almost any location along a pipeline, with the exception of site-specific failure causes such as landslides.

Based on the discussion above, the four failure types used in developing specific risk scenario combinations consist of the following combinations of failure mode and cause:

1. Guillotine Break, Non-Hydrologic
2. Guillotine Break, Hydrologic
3. Minor Leak, Non-Hydrologic
4. Minor Leak, Hydrologic

4.2 Hydrologic Conditions

Two hydrologic conditions are considered in the development of the risk scenario combinations. These include the 100-year flood as a maximum stream flow condition, and a "Sunny Day" or mean flow as a minimum stream flow condition.

Based on the research summarized in Section 2, the 100-year flood is recommended to be the maximum stream flow condition for consideration in analyses of the surface water transport of pipeline spills. The 100-year flood recurrence interval is considered and explicitly mentioned for hazard evaluations of buildings and roadways, for the design of drainage and stream crossing structures, and is also specified as the flood recurrence interval to be considered in the evaluation of valve positioning for pipelines. Spills transported during 100-year flood conditions would generally be expected to experience the highest transport velocities (within and near the channel but not necessarily within the 100-year floodplain); the greatest areal extent of spill spreading (up to the full extent of the 100-year floodplain), and associated high rates of dispersion and elimination of volatiles; and the greatest decreases in concentration due to mixing of the product with floodwaters.

Sunny Day or mean flow conditions are recommended to be the minimum stream flow condition for consideration in surface water spill transport analyses. This hydrologic condition is meant to represent an average or non-flooding stream flow condition. Spills transported during mean flow conditions would generally be expected to experience relatively low transport velocities; limited areal extent of spill spreading (confined to the active channel); relatively low rates of dispersion and elimination of volatiles; and the highest concentrations of spilled product transported within a stream.

The appropriate mean flow value to use in surface water transport analyses will vary depending on the time of year that the spill is assumed to occur (seasonal conditions were discussed in

Section 3.5). For example, mean summer flow conditions will generally be greater than mean winter flow conditions in temperate climates.

The cause and location of postulated spills will govern the type of hydrologic conditions that need to be analyzed. Spills from hydrologic causes such as scour and bank migration should only need to be analyzed for 100-year flood conditions since it is assumed that only low frequency, high magnitude floods will cause those kinds of failures, and that the failures will be located in or near the active stream channel. Spills from non-hydrologic causes such as corrosion or earthquakes should only need to be analyzed for mean flow conditions since the probability of these types of failures occurring coincident with a 100-year flood is unrealistically low.

4.3 Seasonal Conditions

Seasonal conditions must be accounted for in an operator's surface water transport analysis. In arctic, temperate, and arid climatic regions, hydrologic conditions can vary greatly throughout the year. In temperate and arctic climates, ice cover on streams can be a significant factor affecting hydraulics and, consequently, spill transport. Depending on the climatic region that the pipeline is located in, an operator may need to analyze surface water transport of spilled liquids during both open water and ice-affected conditions. 100-year flood conditions are generally assumed to occur during open water conditions. For streams in colder climates, however, the 100-year flood may be generated by spring breakup conditions. Sunny Day or mean flow conditions can occur during either open water or ice-affected conditions.

Ice cover conditions are subdivided into thermal ice and ground-fast ice (aufeis). A thermal ice cover is indicative of significant winter flows and/or water depths in a stream channel. Aufeis is indicative of very low winter flows and/or water depths in the stream channel.

4.4 Specific Risk Scenario Combinations

Specific risk scenario combinations based on various combinations of pipeline failure types, hydrologic conditions, and seasonal conditions have been developed and are presented below in Table 1. As mentioned previously, the appropriate risk scenario combinations to consider will vary from operator to operator, and will be based on the pipeline's age, configuration, and layout; the proximity of the pipeline to stream channels and floodplains; local topography; and regional hydrologic and climatic conditions.

Table 1 Risk Scenario Combinations

No.	Failure Type[1] Failure Mode/Cause	Hydrologic Conditions[2]	Seasonal Conditions[3]
1.	GUILLOTINE/NON-HYDROLOGIC (Corrosion, Landslide, Earthquake, Mechanical Damage, Weld/Seam Failure, etc.)	"Sunny Day" Mean Flow - summer - winter - spring breakup	1.1 Open Water 1.2 Ice Cover
2.	GUILLOTINE/HYDROLOGIC (Scour, Bank Migration)	100-Year Flood	2.1 Open Water 2.2 Ice Cover
3.	MINOR LEAK/NON-HYDROLOGIC (Corrosion, Landslide, Earthquake, Mechanical Damage, Weld/Seam Failure, etc.)	"Sunny Day" Mean Flow - summer - winter - spring breakup	3.1 Open Water 3.2 Ice Cover
4.	MINOR LEAK/HYDROLOGIC (Scour, Bank Migration)	100-Year Flood	4.1 Open Water 4.2 Ice Cover

[1] Failure types 1 & 3 are caused by non-hydrologic factors. Failure types 2 & 4 are caused by hydrologic factors. Whether the cause is hydrologic or not affects the location and zone of influence of the spill and transport characteristics.

[2] "Sunny Day" is equivalent to typical or mean flow, in other words, non-flood conditions.

[3] Seasonal conditions affect the hydraulic characteristics of a stream and thus the zone of influence and the transport of spilled liquids.

As a result of analyses using the risk scenario combinations above, mitigative measures could be developed which might include:

1. Improvements in the detection time of a release,
2. Improvements in operator response time to a detected release,
3. Placement and/or maintenance of remotely actuated valves at critical locations,
4. Pre-deployment of spill response materials,
5. More detailed analytical treatment of the pipeline release hydraulics, and
6. More detailed analytical treatment of topography and surface water transport analytical estimates of water velocity and flow pathways.

Note that the risk scenario combinations presented above are recommended to be the minimum analyzed within an operator's surface water transport analyses. Additional and site specific conditions could prompt the need to analyze additional risk scenario combinations.

5. Surface Hydrology Analysis Approach and Inspector’s Checklist

5.1 Surface Hydrology Analysis Approach

An approach has been developed that OPS inspectors can use in determining operator compliance in their analyses of the surface water transport of spilled liquids. The approach is intended to provide inspectors with explanatory background information and descriptions of analysis steps that an operator should be using in the performance of a technically adequate analysis of surface water spill transport.

The approach is presented as a flow chart with supplemental detailed plates, and is broken down into two general parts - the establishment of the basic analysis inputs and components, and the analysis of results and impacts. In establishing the basics, the appropriate risk scenario combinations are first identified (Step 1) and then, based on the combinations identified, the appropriate spill transport methodologies and spill situations (physical locations of spills) are defined (Step 2).

The analyzing of results and impacts begins with an initial screening to establish the zone of influence of the spill (Step 3). This screening uses preliminary estimates of discharge, water level, and velocity to determine whether there are concerns that HCAs identified in the operator’s segmentation analysis could be affected by a postulated spill. If an HCA is determined to be outside the zone of influence of the postulated spill (for example, if the HCA is determined to be located too far downstream to be affected by the spill, or is determined to be located outside of a stream’s floodplain), then the HCA can be dropped from further consideration. If the screening determines that an HCA could be affected by a postulated spill, however, then further, more detailed hydrologic and hydraulic analyses are required for either open water (Step 4A) or ice-affected (Step 4B) conditions. Analytical tools and computation techniques for detailed surface water transport analyses are also provided. Based on the results of the detailed analyses, if an HCA is identified as not being affected by the postulated spill, it is removed from further consideration. If a detailed analysis determines that an HCA could be affected by a postulated spill, however, then assessment and implementation of mitigative measures would be required, with periodic review and updating of these measures, as necessary.

It is not anticipated that any surface water transport analyses will need to be performed by OPS inspectors. The approach is provided so that inspectors will understand the steps and analysis techniques that an operator should be using in the performance of technically adequate surface water spill transport analyses.

PLATE 1 - FLOW CHART FOR SURFACE WATER TRANSPORT ANALYSIS APPROACH

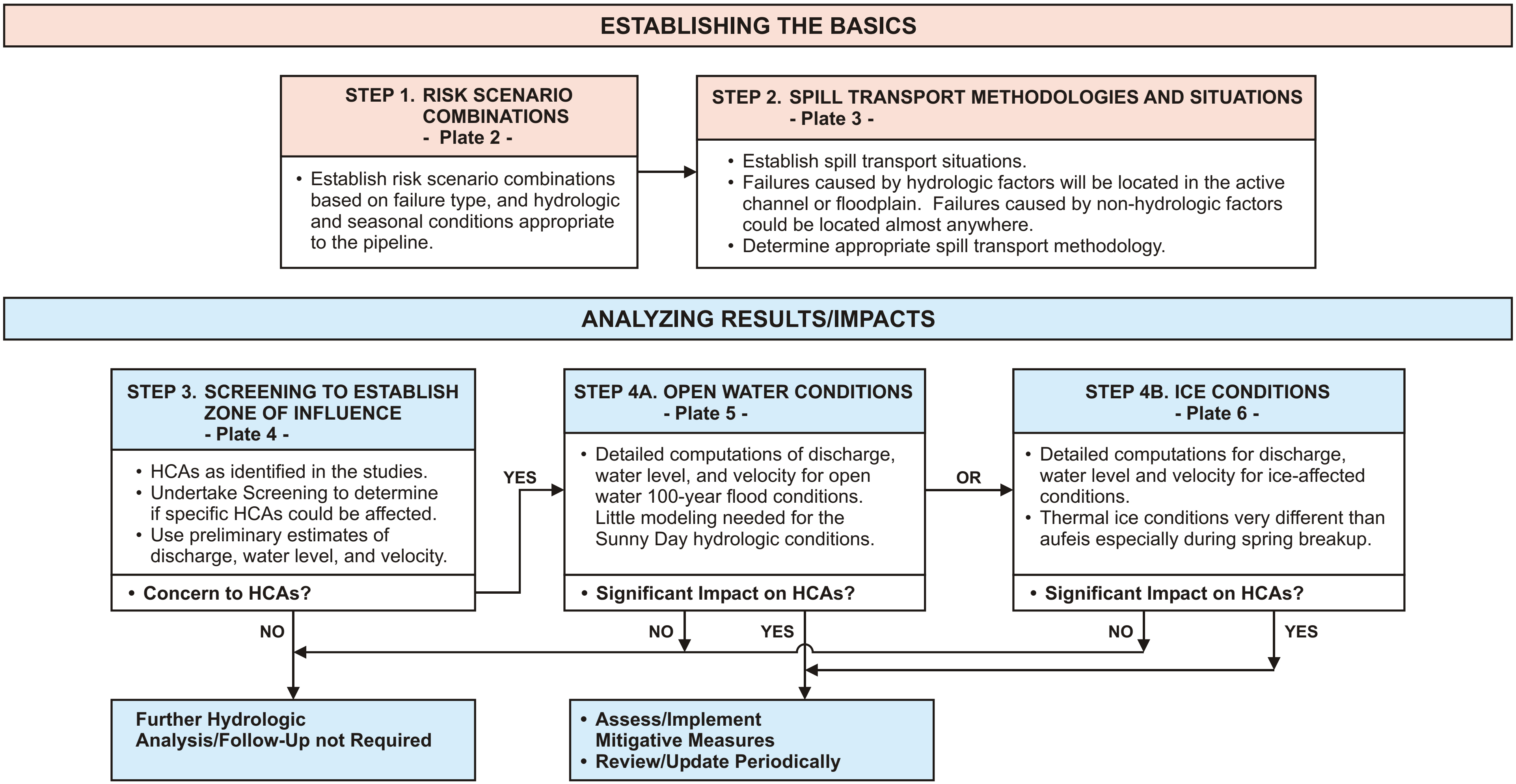


PLATE 2: STEP 1 - RISK SCENARIO COMBINATIONS OF FAILURE TYPE, AND HYDROLOGIC AND SEASONAL CONDITIONS

No.	Failure Type[1] Failure Mode/Cause	Hydrologic Conditions[2]	Seasonal Conditions[3]
1.	Guillotine/Non-Hydrologic (Corrosion, Landslide, Earthquake, Mechanical Damage, Weld/Seam Failure)	"Sunny Day" Mean Flow - summer or - winter or - spring breakup	1.1 Open Water 1.2 Ice Cover
2.	Guillotine/Hydrologic (Scour, Bank Migration)	100-Year Flood Flow	2.1 Open Water 2.2 Ice Cover
3.	Minor Leak/Non-Hydrologic (Corrosion, Landslide, Earthquake, Mechanical Damage, Weld/Seam Failure)	"Sunny Day" Mean Flow - summer or - winter or - spring breakup	3.1 Open Water 3.2 Ice Cover
4.	Minor Leak/Hydrologic (Scour, Bank Migration)	100-Year Flood Flow	4.1 Open Water 4.2 Ice Cover

[1] Failure Types 1 & 3 are caused by non-hydrologic factors. Types 2 & 4 are caused by hydrologic factors. Whether the cause is hydrologic or not affects the location and zone of influence of the spill and transport characteristics. For example a non-hydrologic failure in the overland section will result in transport overland and depending on spill volume, distance, transport characteristics, and response time, it may or may not reach a floodplain or river channel. A hydrologic caused failure would occur only in a floodplain or river channel.

[2] "Sunny Day" is equivalent to typical or mean flow, in other words non-flood conditions.

[3] Seasonal conditions affect the hydraulic characteristics of the river and thus the transport of spilled liquids and Zone of Influence.

Return to Plate 1

PLATE 3: STEP 2 - SPILL TRANSPORT METHODOLOGIES AND SITUATIONS

Location or Extent of Spill	Needs/Considerations/Methodologies
1. River Channel	• Rate of downstream transport will be highly dependent on velocity and, therefore, stream slope and flow rate ("Sunny Day" or 100-year flood). • Screen for Zone of Influence (Plate 4). • Velocities and water levels as per Plate 5 (Open Water) and Plate 6 (Ice-Affected). For Time of Travel Graphs, see Plate 5.
2. Floodplain	• Applicable only for the 100-year flood. For the "Sunny Day" Open Water case, all flow is within the river channel. • Screen for Zone of Influence (Plate 4). • For the 100-year flood use velocities as computed/determined from Plate 5. Velocities and thus transport typically vary substantially in a floodplain due to the influence of vegetation, subchannels and depressions.
3. High Ground/Overland	• Applicable only for "Sunny Day" hydrologic conditions since the probability of an overland failure caused by non-hydrologic factors (due to corrosion, earthquake, etc.) coincident with the 100-year flood is unrealistically rare. • Screen for Zone of Influence (Plate 4). • Transport will be highly dependent on site specific conditions such as: - slope, vegetation and depth of vegetative mat, - micro-topographic variations which can act as mini pools or reservoirs, - thawed or frozen ground conditions - presence, depth, and type of snow cover. • No specific methodology available for these conditions. Evaluate actual field data from spills on similar topographic conditions if available.

Determining Transport Situations

Location of Pipeline Leak	Need to do Transport Analysis for		
	Overland	Floodplain	River Channel
River Channel	–	–	X
Floodplain	–	X	X[1]
Overland	X	X[1]	X[1]

X[1] Depending on whether the spill transport reaches the second 'zone'. For example, Transport Analysis for an Overland Spill would be done for:
- only the Overland Zone if the spill does not reach the Floodplain,
- only the Overland and Floodplain Zones if the spill does not reach the River Channel Zone.

Return to Plate 1

PLATE 4: STEP 3 - SCREENING TO ESTABLISH THE ZONE OF INFLUENCE AND NEED FOR MORE DETAILED EVALUATIONS

PART 1 - ESTABLISH SPILL CHARACTERISTICS

1. Total Volume _____ ft³
2. Release Duration _____ hrs
3. Release Rate _____ ft³/s, (_____ gal/s)
4. Type of Material ____________

PART 2 - ESTIMATE CONCENTRATIONS IN RECEIVING STREAM

1. Sunny Day Flow ____ ft³/s

Concentration = $\frac{\text{Release Rate}}{\text{River Flow}} \times 100 =$ ___ %

2. 100-Year Flood ____ ft³/s

Concentration = $\frac{\text{Release Rate}}{\text{River Flow}} \times 100 =$ ___ %

1. Sunny Day Flow Estimated as Follows:
- Flow = width x average depth x 0.80 surface velocity where:
  - width = as measured in the field or from maps.
  - average depth = as sounded from a boat or from a bridge or from local knowledge or from wading.
  - surface velocity = as measured by timing a float (wood or orange) along a specific distance.

2. 100-Year Flood Flow Estimated as Follows:
- If previously computed for another location on the same river (for other private or public purposes).
  - use "as is" if the drainage area is within 10% of that at the spill site.
  - if the drainage areas are different by more than 10%, adjust the computed flow value by an amount equal to the difference in drainage areas.
- If not previously computed elsewhere on the river
  - 10X the Sunny Day Flow or 5X the Bankfull Flow with it estimated in a similar manner to the Sunny Day Flow

(Note these estimates are not to be used for Steps 4A or 4B)

PART 3 - SCREEN TO DETERMINE NEED FOR DETAILED ANALYSIS

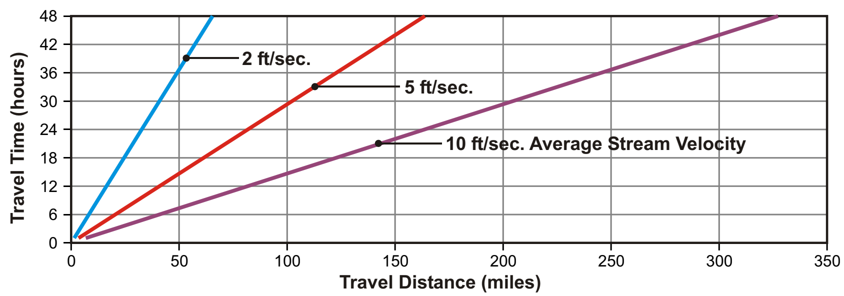
ISSUE/CONCERN	BASIS AND METHOD FOR SCREENING	RESULTS? FOLLOW-UP NEEDED?
1. Spill Concentration in the Flow	• Historic examples and literature of the impact of concentration levels on aquatic resources and vegetation.	• Is the computed concentration a concern? • YES, go to Step 4A or Step 4B, Plate 1 • NO, no need to evaluate further.
2. Downstream Extent of the Spill	• Historic examples and literature of downstream impacts (with high volatility, concentrations decrease as you travel downstream). • Any data on downstream travel distances?	• Is the computed concentration a concern to the first HCA downstream? • YES, go to Step 4A or Step 4B, Plate 1 • NO, no need to evaluate other HCA(s) further downstream (see Plate 1).
3. Volatility of the Fluid (re: Safety)	• Historic examples and literature of similar spills. Volatility dependent on temperature?	• Is the computed concentration a concern? • YES, go to Step 4A or Step 4B, Plate 1 • NO, no need to evaluate further.

Return to Plate 1

PLATE 5: STEP 4A - HYDROLOGIC & HYDRAULIC EVALUATIONS FOR OPEN WATER CONDITIONS

Hydrologic Scenarios/Conditions	Computational Needs/Considerations and Methodologies		
	Discharge	**Water Level**	**Main Channel Velocity**
1. Sunny Day (Mean/Typical Flow)	• As observed/noted in the field. • The discharge magnitude is not important per se but rather the resultant water level and velocity.	• Main channel water level as observed/measured in the field. • No additional computations or modeling required.	• Main channel velocity as observed/measured in the field. • Measurement of surface velocities using floats is acceptable. • No additional computations or modeling required.
2. 100-Year Flood (Max. Daily Flow)	• Extrapolate from analysis of flow data at a government flow measurement gage location or from hydrologic modeling done elsewhere on the stream. If these are not available, use regional analysis to compute the 100-year flood. • An alternate approach is to use the flood of record on the stream if close to or larger than the 100-year event. • Use flood frequency analysis to generate peak values (Appendix B). • Use hydrologic models (Appendix C): - to determine the duration of high flows or, - to compute flows from rainfall if flow data are inadequate.	• Extrapolate from other studies done on the stream, as appropriate. If not available, proceed as indicated below. • Compute from: - channel and floodplain surveys, - 1D hydraulic models (Appendix D). Only in major deltas or very wide floodplains will a 2D model be valuable and useful. - roughness and expansion/contraction coefficients. • Use known data at bridges and observable high water levels wherever possible as a check on all computations.	• Extrapolate from other nearby studies, as appropriate. If not available and if necessary to determine impacts on an HCA, then proceed as indicated below. • Velocities in the channel and floodplain are a direct output from 1D hydraulic models (Appendix D). • Cross sections to be sufficiently detailed and subdivided in the model calculations to compute variable velocities in the main channel and in the floodplain.

Travel Distance for Various Time Periods and Various Stream Velocities



Return to Plate 1

PLATE 6: STEP 4B - HYDROLOGIC & HYDRAULIC EVALUATIONS FOR ICE-AFFECTED CONDITIONS

Hydrologic and Ice Conditions	Computational Needs/Considerations and Methodologies		
	Discharge (Flow)	**Water Level/Top of Ice**	**Velocity**
1. Thermal Ice Cover - Typical Winter Flow Conditions. "Sunny Day" Flow	• As observed/noted in the field. The discharge magnitude is not important per se but rather the water level and velocity as noted.	• As observed/noted in the field for typical winter flow and ice conditions. • No additional computations or modeling required.	• As measured under the ice or in open water reaches. Measurement of surface velocities using floats is acceptable. • No additional computations or modeling required.
2. Thermal Ice Cover - Spring Breakup Conditions. “Sunny Day” Flow or 100-Year Flood	• For streams in colder climates, the 100-year flood may be generated by breakup conditions. • Use 100-year flood as determined from recorded flow data or as generated from adjacent watersheds.	• Ice jam potential and extent highly dependent on climatic rather than hydrologic conditions. • Highly site specific as it depends on: - releases of ice jams from upstream, - potential of ice jam in the area of interest. • Use historic data for the river of interest - more reliable than theoretical calculations. Historic ice jam levels often visible in the floodplain (debris accumulation and damage to trees).	• Velocities extremely variable due to: - the influence of the ice, - impact of 'flood wave' as a result of the release of an ice jam upstream. • Where possible obtain values from historic observations and local knowledge.
3. Aufeis/Ground Fast Ice - Winter or Breakup Conditions. “Sunny Day” Flow	• Indicative of very low winter flow - thus no need to compute flow magnitude. • During breakup, use typical/mean flows for the breakup period while the ice cover is ground-fast.	• Ice levels and thus water levels over ice vary from year-to-year and from location to location. • If available, use local information regarding the potential height of the aufeis and from this estimate the water level.	• In winter, little or no velocity. In breakup over ice, velocity is about 50% higher than for similar flow conditions.

Return to Plate 1

5.2 Inspector's Checklist

Based on the approach described in Section 5.1, a one-page inspector's checklist has been developed that guides an OPS inspector through an evaluation of an operator's surface water transport analysis submittal. The checklist allows an inspector that is familiar with the approach described in this report to systematically go through an operator's submittal and check off whether or not an adequate analysis has been performed. It is recommended that operators be given access to this report and the inspector's checklist so that they understand what an OPS inspector will be looking for in their submittal review. The checklist is presented below along with checklist instructions that outline some of the important features of the checklist.

OPS TTO No. 3 - SURFACE HYDROLOGY ANALYSIS - INSPECTORS CHECKLIST

1.0 BASIC INFORMATION

Operator ______________________ Pipeline Name ______________________

Address ______________________ Pipeline Area/Segment ______________________

______________________ MP __________ to MP __________

Phone No. ______________________ Inspection Format Office, Field or Aerial, Etc., Or some Combination

Operator Staff/Representatives Interviewed ______________________

Inspection No. ______________________ Previous Inspection No./Date ______________________

2.0 ESTABLISH HYDROLOGIC CONDITIONS/SETTINGS

2.1 Names of Rivers/Creeks crossed __________ __________ __________

(Identify by Mileposts) __________ __________ __________

2.2 Location of Pipeline in and/or Parallel to Floodplains/River MP __________ to MP __________

3.0 SCREENING TO DETERMINE NEED FOR DETAILED ANALYSIS

	Guillotine Failure		Minor Leak	
	Non Hydrol.	Hydrol.	Non Hydrol.	Hydrol.
3.1 CONCENTRATION OF SPILL IN RIVER FLOW				
3.1.1 Release Volume/Rate Computed?				
3.1.2 Sunny Day Flow or 100- Year Flood				
- River Flow Computed?				
- Spill Concentration Computed?				
3.2 POTENTIAL ZONE OF INFLUENCE OF SPILL				
3.2.1 Spill Mitigative Measures in Place?				
3.2.2 Sunny Day Flow				
- Stream Width Established?				
- Velocity Estimated?				
- Travel Distances Estimated?				
3.2.3 100-Year Flood				
- Stream Width Established?				
- Velocity Estimated?				
- Travel Distances Estimated?				
3.3 FOLLOW-UP NEEDED? (If Yes, go to 4.0 & 5.0) (If No, go to 5.0)				
3.3.1 Sunny Day Flow				
- HCAs Potentially Affected?				
3.3.2 100-Year Flood				
- HCAs Potentially Affected?				

4.0 DETAILED ANALYSIS (If Needed)

	Open Water		Ice	
	Guillotine	Minor Leak	Guillotine	Minor Leak
4.1 SUNNY DAY FLOW - NON HYDROLOGIC FAILURE				
4.1.1 River Flow Computed/Estimated?				
4.1.2 Spill Concentration Computed?				
4.1.3 Water Level Computed?				
4.1.4 Velocity Computed?				
4.1.5 Travel Dist. Determined vs Time?				
4.2 100-YEAR FLOOD - HYDROLOGIC FAILURE				
4.2.1 River Flow Computed/Estimated?				
4.2.2 Spill Concentration Computed?				
4.2.3 Water Level Computed?				
4.2.4 Velocity Computed?				
4.2.5 Travel Dist. Determined vs Time?				

5.0 SUMMARY OF IMPACTS

5.1 HCAs AFFECTED BY FAILURE DURING SUNNY DAY FLOW

5.1.1 Guillotine __________ __________

5.1.2 Minor Leak __________ __________

5.2 HCAs AFFECTED BY FAILURE DURING 100-YEAR FLOOD

5.2.1 Guillotine __________ __________

5.2.2 Minor Leak __________ __________

6.0 SIGN OFF/DISTRIBUTION

Date of Inspection ______________________ Date of Report ______________________

Inspector ______________________ ______________________

Print Name Signature

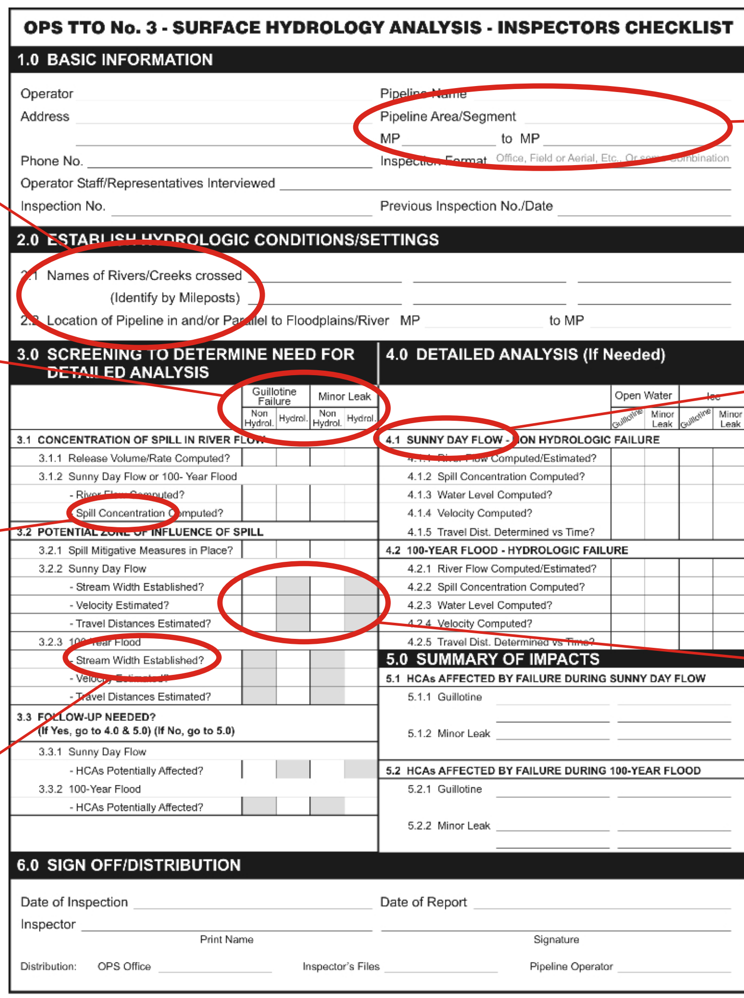
Distribution: OPS Office __________ Inspector's Files __________ Pipeline Operator __________

CHECKLIST INSTRUCTIONS

GENERAL

1. Intended as a tool/checklist for the inspection and documentation process. The overall TTO No. 3 report provides the necessary background.

2. A short report by the Inspector is assumed to typically accompany the Checklist to discuss the inspection results in greater detail as necessary.



OPS TTO No. 3 - SURFACE HYDROLOGY ANALYSIS - INSPECTORS CHECKLIST

1.0 BASIC INFORMATION

Operator ______ Pipeline Name ______
Address ______ Pipeline Area/Segment ______
______ MP ______ to MP ______
Phone No. ______ Inspection Format ______ Office, Field or Aerial, Etc. Or some combination
Operator Staff/Representatives Interviewed ______
Inspection No. ______ Previous Inspection No./Date ______

2.0 ESTABLISH HYDROLOGIC CONDITIONS/SETTINGS

2.1 Names of Rivers/Creeks crossed (Identify by Mileposts) ______
2.2 Location of Pipeline in and/or Parallel to Floodplains/River MP ______ to MP ______

3.0 SCREENING TO DETERMINE NEED FOR DETAILED ANALYSIS

	Guillotine Failure: Non Hydrol.	Guillotine Failure: Hydrol.	Minor Leak: Non Hydrol.	Minor Leak: Hydrol.
3.1 CONCENTRATION OF SPILL IN RIVER FLOW				
3.1.1 Release Volume/Rate Computed?				
3.1.2 Sunny Day Flow or 100- Year Flood				
- River Flow Computed?				
- Spill Concentration Computed?				
3.2 POTENTIAL ZONE OF INFLUENCE OF SPILL				
3.2.1 Spill Mitigative Measures in Place?				
3.2.2 Sunny Day Flow				
- Stream Width Established?				
- Velocity Estimated?				
- Travel Distances Estimated?				
3.2.3 100-Year Flood				
- Stream Width Established?				
- Velocity Estimated?				
- Travel Distances Estimated?				
3.3 FOLLOW-UP NEEDED? (If Yes, go to 4.0 & 5.0) (If No, go to 5.0)				
3.3.1 Sunny Day Flow				
- HCAs Potentially Affected?				
3.3.2 100-Year Flood				
- HCAs Potentially Affected?				

4.0 DETAILED ANALYSIS (If Needed)

	Open Water: Guillotine	Open Water: Minor Leak	Ice: Guillotine	Ice: Minor Leak
4.1 SUNNY DAY FLOW - NON HYDROLOGIC FAILURE				
4.1.1 River Flow Computed/Estimated?				
4.1.2 Spill Concentration Computed?				
4.1.3 Water Level Computed?				
4.1.4 Velocity Computed?				
4.1.5 Travel Dist. Determined vs Time?				
4.2 100-YEAR FLOOD - HYDROLOGIC FAILURE				
4.2.1 River Flow Computed/Estimated?				
4.2.2 Spill Concentration Computed?				
4.2.3 Water Level Computed?				
4.2.4 Velocity Computed?				
4.2.5 Travel Dist. Determined vs Time?				

5.0 SUMMARY OF IMPACTS

5.1 HCAs AFFECTED BY FAILURE DURING SUNNY DAY FLOW
5.1.1 Guillotine ______
5.1.2 Minor Leak ______

5.2 HCAs AFFECTED BY FAILURE DURING 100-YEAR FLOOD
5.2.1 Guillotine ______
5.2.2 Minor Leak ______

6.0 SIGN OFF/DISTRIBUTION

Date of Inspection ______ Date of Report ______
Inspector ______ Print Name ______ Signature
Distribution: OPS Office ______ Inspector's Files ______ Pipeline Operator ______

Attach additional sheets if necessary.

If entire pipeline is not inspected, indicate here. If distinctly different segments are inspected that affect different HCAs, complete a checklist for each segment.

Non-Hydrologic
- Failure due to non-hydrologic causes (corrosion, etc.)

Hydrologic
- Failure due to river scour or bank migration.

Sunny Day, as defined in the report, basically represents a typical flow.

Spill Concentration assumes it is fully mixed in the river. In reality, a spill may not immediately mix in a wide, deep and low velocity stream.

Not Applicable. In the rest of the boxes, indicate **Y** or **N** for "work done" and "work not done" respectively.

Travel Distance estimate - assume a maximum duration of 2 days.

6. Example Scenarios and Surface Water Transport Analyses

Two example scenarios have been developed in order to show how the surface water transport analysis approach and inspector's checklist presented in Section 5 might be used by an OPS inspector reviewing an operator's surface water transport submittal. One of the two example scenarios models potential pipeline spills in a rural setting (McGrath, Alaska) while the other example models spills in an urban setting (Fairbanks, Alaska).

The pipelines and associated facilities described in the two example scenarios are purely hypothetical. Their development and descriptions have been based on experience with similar pipeline facilities in the region, and are felt to provide realistic examples of facilities that could exist at the two locations.

The modeling, data analysis, and field investigation results presented in the surface water transport analysis examples are based on existing studies, and hydrologic and hydraulic experience on similar projects in the region. No actual modeling or field investigations have been performed in the development of the example surface water transport analyses.

The two example scenarios are presented below.

6.1 Example Scenario I. Rural Pipeline Spill Scenario - McGrath, Alaska

6.1.1 McGrath Overview

The town of McGrath is located in Interior Alaska 220 air miles northwest of Anchorage and 270 air miles southwest of Fairbanks. The town is located on the inside of a large meander bend on the Kuskokwim River directly south of the river's confluence with the Takotna River. The community is accessible by either air or boat. There is no road access to the community. McGrath is shown on Figure 1 (attached at the end of this section).

The McGrath area has a cold, continental climate. Average summer temperatures range from 62^{o} to 80^{o} Fahrenheit (^{o} F), while winter temperatures range from -64^{o} to 0^{o} F. Precipitation is light, averaging 10 inches per year, including an average annual snowfall of 86 inches.

6.1.2 Pipeline/Facility Description

The hypothetical pipeline and associated facilities consist of two storage tank facilities, a connecting pipeline, and a fuel loading dock on the Kuskokwim River. The first storage tank facility consists of 180,000 gallons of diesel fuel storage capacity in the form of skid-mounted, above ground, double-walled steel tanks located approximately 150 feet inland from the shore of the Kuskokwim River at Sterling Landing (see Figure 1). The storage tank facility is linked to a mining operation approximately seven miles due west by a 3-inch diameter buried steel pipeline. Fuel is pumped from the storage facility to a 10,000-gallon skid-mounted, double-walled steel storage tank at the mine site to supply fuel for the mining operation. The mine operates from June through October, and fuel is pumped through the pipeline approximately 15 times during that period. When not in use, the pipeline remains full of fuel. The pipeline is equipped with a gate valve and check valve where the pipeline exits the tank farm at Sterling Landing, and also has a gate valve at the terminus of the pipeline at the mining site. During use of the pipeline, an operator is stationed at the tank farm to operate the pump, and another operator is stationed near the 10,000-gallon tank at the mine site to operate the gate valve at the pipeline terminus. The operators are in radio contact during transfer operations.

A short section of 4-inch diameter pipeline also extends from the storage tanks at Sterling Landing to the edge of the Kuskokwim River and out onto a fuel loading dock. This is where the fuel delivery barge docks and pumps fuel into the storage tanks once each spring (typically in early June). This short section of pipeline is equipped with gate valves at both ends and a check valve on the dock. Following fuel delivery, the barge operator drains the pipeline back into the barge and runs a foam cleaning pig through the pipeline with compressed air.

6.1.3 McGrath High Consequence Area Summary

After performing a pipeline segmentation analysis, the following HCAs were identified in the region of interest. The sources of the HCA data listed below include the U.S. Department of Transportation's (USDOT's) National Pipeline Mapping System (NPMS) database, and the Alaska Department of Environmental Conservation (ADEC).

McGrath Other Populated Area HCA

McGrath is incorporated as a Second Class City. The McGrath Other Populated Area (OPA) HCA boundary is defined by the community's corporation boundary, which encompasses 48.9 square miles of land and 5.7 square miles of surface water bodies. A portion of the McGrath OPA HCA is shown on Figure 1 as an orange box surrounding the community.

The current population of McGrath is 401, certified as of December 2001, and consists of 178 households. Approximately half of the population is of Alaska Native heritage. McGrath has a diverse cash economy and functions as a regional center offering a variety of employment opportunities including transportation and communications. The community also serves as a supply center for this region of Interior Alaska. Many local families rely upon subsistence hunting and fishing for a major portion of their food supply. Subsistence wildlife populations include salmon, ducks, geese, moose, caribou, bears, and rabbits.

Adverse effects to the McGrath OPA HCA from a pipeline spill would include, among other things, toxic effects from a vapor cloud generated as volatiles are released from the spilled product; soiling of and lethality to local wildlife populations used by the community as subsistence food sources; and fire damage to community structures and surrounding forests from an ignited product release.

McGrath Unusually Sensitive Area Community Water System Drinking Water HCA

The City of McGrath operates a piped water system that serves nearly all of the 178 households in the community. A small number of homes have private water wells or haul water from nearby surface waters. Water is drawn from the Kuskokwim River during the summer months when the river is ice-free. The public water supply intake is located a short distance upstream of the community. A large system of cisterns is filled prior to freeze-up to provide water over the winter months.

The McGrath Unusually Sensitive Area (USA) Community Water System (CWS) Drinking Water (DW) HCA consists of all surface waters within a five-mile radius of the community center. The HCA includes all lands within a 1,000-foot buffer from the edge of surface water bodies (ponds, lakes, and streams) located within the five-mile-radius HCA boundary. The light blue (cyan) lines on Figure 1 depict a portion of the McGrath Drinking Water HCA.

Adverse effects to the McGrath USA CWS Drinking Water HCA from a pipeline spill would consist of the contamination of surface waters used as drinking water sources by the community. This would include not just the Kuskokwim River, which serves as the main community water supply, but also smaller water bodies from which isolated households withdraw water.

Kuskokwim River Commercially Navigable Waterway HCA

The Kuskokwim River, with a drainage area of 11,700 square miles at McGrath, has its source at the confluence of the North and South Forks of the Kuskokwim River. The Kuskokwim and Yukon Rivers are the two major trunk streams draining the entire central Alaska region. The Kuskokwim River meanders through the broad, flat country around and downstream of McGrath, as it winds its way to the Bering Sea, eventually skirting the southern portion of the lake-filled and boggy Yukon-Kuskokwim Delta. Breakup of the river usually occurs in mid-May, and freeze-up typically occurs in October (USACE, 1977).

McGrath is the northernmost point on the Kuskokwim River accessible by large riverboats. Commercial waterborne transportation on the Kuskokwim River can be summarized as follows:

1. A private regional operator out of Bethel, approximately 400 miles downstream
2. A government services contractor based out of Seattle
3. Resident operators with small barges serving nearby villages

Essentially all freighted goods received in McGrath by barge originate either directly or indirectly in Bethel. Goods originating in Seattle are transferred to smaller vessels for travel up the Kuskokwim River. Approximately 95% of the freight shipped to McGrath consists of bulk fuel for use by local consumers.

The Kuskokwim River Commercially Navigable Waterway (CNW) HCA is shown as a dark blue line on Figure 1. The upstream terminus of the HCA is located at McGrath. The HCA extends from McGrath to the mouth of the river in the Yukon-Kuskokwim Delta.

Adverse effects to the Kuskokwim River CNW HCA from a pipeline spill would consist of, among other things, toxic effects on boat traffic from a vapor cloud generated as volatiles are released from the spilled product; possible fire danger to boat traffic from an ignited product release; and the interruption of commercial navigation schedules as a result of spill response activities.

Additional HCAs Downstream from McGrath That Could Be Affected By A Pipeline Spill

A spill traveling down the Kuskokwim River could potentially adversely affect a number of identified downstream HCAs. These additional downstream HCAs are summarized below along with their downstream distances from McGrath.

Table 2 HCAs Downstream from McGrath

HCA	Distance
Stony River OPA HCA	135 miles
Sleetmute OPA HCA and USA DW HCA	155 miles
Red Devil OPA HCA	170 miles
Crooked Creek OPA HCA	197 miles
Chuathbaluk OPA HCA and USA DW HCA	265 miles
Aniak OPA HCA and USA DW HCA	276 miles
Upper Kalskag OPA HCA	308 miles
Lower Kalskag OPA HCA and USA DW HCA	310 miles
Tuluksak OPA HCA and USA DW HCA	354 miles
Akiak OPA HCA	375 miles
Akiachak OPA HCA and USA DW HCA	385 miles
Kwethluk OPA HCA and USA DW HCA	392 miles
Bethel OPA HCA and USA DW HCA	405 miles

6.1.4 McGrath Example Spill Scenarios and Surface Water Transport Analyses

The following example spill scenarios and surface water transport analyses are meant to represent scenarios and analyses that might be developed and performed by the operator of the hypothetical McGrath pipeline. Following each example is a brief discussion of how the surface water transport analysis approach could be used in an evaluation of the analysis. Readers should keep in mind that the pipeline facilities and spill scenario descriptions are purely hypothetical. Additionally, readers should keep in mind that no actual analyses have been performed for the examples. The analysis results presented are felt to be reasonable and are based on either existing studies or the experience of the authors.

McGrath Spill Scenario and Surface Water Transport Analysis No. 1

The fuel loading dock and fuel storage tank at Sterling Landing are both located along the outside of a tight meander bend of the Kuskokwim River. Active erosion and bank migration have been noted along the bend. A bank migration analysis using aerial photogrammetry determined that migration of the edge of the bank could reach the fuel storage tank within the life of the project. The result of this could be the undermining of the tank, causing it to fall into the river and spill its contents. In addition, the 3-inch connecting pipeline would be ruptured and also spill its contents into the river.

An analysis was performed to determine the potential adverse effects on downstream HCAs of this failure scenario. The analysis included the following assumptions:

- The worst-case scenario spill volume equals the full storage tank capacity (180,000 gallons) and the volume of fuel contained in the ruptured pipe from its high point above the river to the tank site (7,000 gallons in 3.6 miles of pipe) for a total of 187,000 gallons of fuel spilled.

- The erosion and spill event occurs as a result of 100-year flooding conditions.

For the flooding conditions assumed above, the spill will quickly spread down and across the active channel of the river as well as into the river's floodplain.

A 1977 U.S. Army Corps of Engineers study (USACE, 1977) provides estimated flood values, water surface elevations, and maps of areas inundated by flooding for the community of McGrath. The downstream boundary of the 1977 study area is approximately 10 river miles upstream from Sterling Landing. Examination of photography and mapping shows no major tributaries entering the river between McGrath and Sterling Landing, and suggests that channel and floodplain characteristics are consistent enough to extrapolate the information from McGrath downstream to Sterling Landing. Therefore, the expenditure of effort and resources that would be involved in modeling flood flows on a river the size of the Kuskokwim will not be necessary.

The 100-year flood magnitude for the Kuskokwim River at McGrath has been estimated at 110,000 cubic feet per second (cfs). Channel velocities during the 100-year flood are estimated to be approximately 4.5 feet per second (fps) while floodplain velocities are estimated to average less than 1 fps.

By extrapolating the computed slope of the 100-year flood water surface downstream to Sterling Landing and beyond, flood inundation mapping was produced. Field verification was performed by inspecting flood marks and damage in the forest along the edge of the floodplain.

A zone of influence screening analysis ("could affect" determination) was also performed which factored in travel time in both the channel and overbank areas, and reductions in spill volumes and concentrations based on dispersion, volatilization, and entrapment by floodplain vegetation. Based on the zone of influence analysis, the HCAs that could potentially be adversely affected by the spill include the McGrath OPA HCA and the Kuskokwim River CNW HCA.

Potential adverse effects to the McGrath OPA HCA would be restricted to (1) toxic effects from a vapor cloud generated as volatiles are released from the spilled product and blown toward the community by prevailing southwesterly winds, and (2) the soiling of and lethality to local wildlife populations used by the community as subsistence food sources. The effects of the vapor cloud would begin shortly after the occurrence of the spill and be relatively short-lived. Effects on local wildlife populations used as subsistence food sources would also begin shortly after the occurrence of the spill but could be persistent.

Potential adverse effects to the Kuskokwim River CNW HCA would consist of toxic effects on boat traffic from a vapor cloud generated as volatiles are released from the spilled product, and possible fire danger to boat traffic from an ignited product release. These effects would be short-lived.

A spill transport and spreading analysis was performed based upon the physical properties of the spilled liquid, the extent of the floodplain determined from the flood inundation mapping efforts, and the extrapolated water velocities for the channel and floodplain.

Based on the surface water transport and zone of influence analyses, a mitigation plan was developed that included placing a buffer zone around the fuel storage tank, and regularly surveying and monitoring the stream bank upstream and downstream of the tank. When and if the migrating bank moves within the buffer zone, plans would be implemented to move the storage tank to a new and safer upland location.

Using the Surface Water Transport Analysis Approach

Step 1 (from Plate 2): The Risk Scenario Combination used in the analysis is No. 2 - a guillotine break from a hydrologic cause. For this risk scenario combination, the appropriate hydrologic conditions to analyze are the 100-Year Flood. The appropriate seasonal conditions are Open Water. The analysis is consistent with these requirements.

Step 2 (from Plate 3): The spill transport situations to be analyzed include both the active channel and the floodplain. The analysis is consistent with these requirements. The appropriate spill transport methodologies to use for both the active channel and floodplain will be for Open Water conditions. The analysis is consistent with these requirements.

Step 3 (from Plate 4): The zone of influence screening seems appropriate in the determination of the HCAs that could be affected by the spill. The 100-year flood discharge and velocities did not need to be estimated since the values for McGrath were deemed appropriate for use.

Step 4A (from Plate 5): Discharge data were extrapolated to the area of interest. Since the Sterling Landing location is so close to McGrath and no major tributaries enter the river between those two locations, the extrapolation seems appropriate. Water level data were extrapolated to the area of interest. This might not be appropriate in some cases but, given the performance of field verification of flood levels and the similarity of channel and floodplain characteristics along this reach of the river, the extrapolation is probably acceptable. Velocity data were extrapolated to the area of interest. Again, this might not be appropriate in some cases but, given the similarity of channel and floodplain characteristics, the extrapolation is probably acceptable.

<u>Conclusions Based on Use of the Surface Water Transport Analysis Approach</u>: It is verified that the operator produced a water transport analysis that was technically adequate and consistent with its program requirements.

<u>McGrath Spill Scenario and Surface Water Transport Analysis No. 2</u>

Because the mining operation shuts down in the winter, there are concerns about a spill occurring when no mine site personnel are present to detect or respond to the spill. The following analysis was performed to address this possibility, and was set up with the following assumptions:

- The gate valve at the terminus of the 3-inch pipeline at the head of Candle Creek develops a leak in the valve seal as a result of age and extreme cold temperatures.
- The leakage rate is less than 0.1 gallons per minute.
- The mining crew has departed for the winter months and the leak goes undetected until the following spring (early May) when the mining crew returns for the summer season.
- The leak allows all the fuel in the pipeline between the top of the ridge above the mine site and the terminus to spill into the headwaters of Candle Creek (2,520 gallons of fuel in 1.3-miles of pipeline).
- Candle Creek does not flow in the winter due to extremely cold temperatures and underlying permafrost soils.
- The spill is trapped within the snowpack until spring breakup when it flows down Candle Creek.

The analysis is an office exercise, and no field data are collected. The analysis assumes that the spill travels by overland flow within the melting snowpack in the spring, and that the spill enters Candle Creek when relatively high magnitude spring breakup flows are occurring.

A zone of influence ("could affect") screening analysis determines that a portion of the spill is reduced through processes of volatilization and evaporation during the long, warm spring days when breakup begins. The "could affect" analysis also determines that downstream HCAs that could be adversely affected by the spill include the Kuskokwim River CNW HCA, and the McGrath USA CWS Drinking Water HCA.

Spring breakup flows are calculated to be 5 cfs at the point where the spill, already reduced in volume from the processes described above, is presumed to enter the creek. The flows are computed using regional regression equations developed by the U.S. Geological Survey Water Resources Division. A HEC-RAS water surface profile model is set up using topographic data from extensive placer exploration surveys carried out along the Candle Creek drainage.

At the point where Candle Creek joins the Takotna River north of McGrath, the flow is computed to be 180 cubic feet per second and spill concentrations are determined to be too low to have an effect on any identified HCAs. Based on the analysis results, no mitigation measures are planned beyond normal inspection and maintenance of valves on the facilities.

Using the Surface Water Transport Analysis Approach

Step 1 (from Plate 2): The Risk Scenario Combination used in the analysis is No. 3 - a minor leak from a non-hydrologic cause. For this risk scenario combination, the appropriate conditions to analyze are the Mean Winter ("Sunny Day") Flow with Ice-affected Conditions. The operator's analysis instead used relatively high magnitude spring breakup flows during Open Water Conditions which would tend to lower spill concentrations relative to water volumes. Additionally, no field work was performed to firmly establish that Candle Creek does not flow in the winter. The operator should possibly be directed to either rerun the analysis with the assumption that Candle Creek does flow in the winter, or to produce further data to support the assumption that there is no winter flow in the creek.

Step 2 (from Plate 3): The spill transport situations to be analyzed include overland, floodplain, and the active channel. The analysis is consistent with these requirements. The appropriate spill transport methodologies to use for both the active channel and floodplain will be for Ice-affected conditions, per the discussion for Step 1. The analysis is, therefore, not consistent with these requirements.

Step 3 (from Plate 4): The zone of influence analysis should be modified to include the possibility that Candle Creek flows under an ice cover in the winter, and the spilled liquid drains into the creek during this period.

Step 4B (from Plate 6): Hydrologic and Ice Conditions No. 1 would be the appropriate one for the operator to use. Recommend the collection of field data, per the discussion for Step 1.

<u>Conclusions Based on Use of the Surface Water Transport Analysis Approach</u>: Additional work is required on the part of the operator before it can be verified that the surface water transport analysis was technically adequate and consistent with its program requirements. Further analysis and field efforts, as described in the discussion above, should probably be required. The zone of influence analysis will probably also need to be expanded to reflect the assumptions of the new surface water transport analysis.

6.2 Example Scenario II. Urban Pipeline Spill Scenario - Fairbanks, Alaska

6.2.1 Fairbanks Overview

The city of Fairbanks is located in Interior Alaska on the banks of the Chena River in the Tanana Valley. The Chena River joins the Tanana River near the southwest end of the community. Fairbanks is located to the north of Anchorage, 45 minutes by air and 358 miles by road. Fairbanks is shown on Figure 2 (attached at the back of this section).

The Fairbanks area experiences seasonal temperature extremes. Winter temperatures average -12^{o} F while summer temperatures average 61^{o} F. Temperatures have been recorded as low a -78^{o} F in mid-winter, and as high as 93^{o} F in summer. The Fairbanks area receives an average annual precipitation of 11.3 inches.

6.2.2 Pipeline/Facility Description

The hypothetical pipeline and associated facilities consist of an 8-inch diameter pipeline that extends from a tank farm located adjacent to the Fort Wainwright Airfield, through the center of Fairbanks commercial and residential areas, to a tank farm at the Fairbanks International Airport (FIA). The tank farm at the Fort Wainwright Airfield stores jet fuel for use by the military, and is supplied by railcar from a refinery located approximately 13 miles to the southwest. The 8-inch pipeline transfers fuel from the Fort Wainwright tank farm to the FIA tank farm. The Fort Wainwright Tank Farm stores 2.3 million gallons of jet fuel and the FIA tank farm stores 1.8 million gallons. Transfers through the pipeline occur an average of four times per week, and the pipeline remains full between transfer operations. The 17-year-old pipeline is protected by an impressed current cathodic protection system.

The 8-inch pipeline is buried at an average depth of four feet, has gate valves at each end, and a check valve just downstream of the pumps at the Fort Wainwright Airfield. The pipeline also has four additional buried gate valves where it traverses close to the Chena River (Figure 2). These gate valves are closed following fuel transfer operations to limit the amount of fuel that would spill in case of a pipe failure along the route. At two locations, the pipeline passes within 100 feet of the bank of the Chena River.

Transfer operations are normally conducted during daylight hours with operators from Fort Wainwright and the FIA in phone and radio contact during transfers. The entire length of the pipeline right-of-way is visually inspected once each week for any signs of leaks.

6.2.3 Fairbanks High Consequence Area Summary

After performing a pipeline segmentation analysis, the following HCAs were identified in the region of interest. The sources of the HCA data listed below include the USDOT's NPMS database, the ADEC, and the Alaska Natural Heritage Program, administered by the University of Alaska Anchorage.

<u>Fairbanks High Population Area HCA</u>

With a population of 30,224 (as of December 2001), Fairbanks is Alaska's second largest city and serves as a regional service center for a diverse economy consisting of city, borough, State, and Federal government services; and transportation, communication, manufacturing, financial, and regional medical services. Approximately 50% of the employment is in government services at Eielson Air Force Base and Fort Wainwright. The University of Alaska Fairbanks is another major employer. Residents are primarily non-Native. The City of Fairbanks is located within the Fairbanks North Star Borough which has total population of 82,840, certified as of December 2001.

Fairbanks is incorporated as a Home Rule City. The Fairbanks HPA HCA boundary is defined by the community's corporation boundary. A portion of the boundary of the Fairbanks HPA HCA is shown on Figure 2 by a magenta outline with a hatched pattern inside.

Adverse effects to the Fairbanks HPA HCA from a pipeline spill would include, among other things, toxic effects from a vapor cloud generated as volatiles are released from the spilled product, and fire damage to community structures and surrounding forests from an ignited product release.

<u>Fairbanks USA Wellhead Protection Area Drinking Water HCA</u>

The City of Fairbanks operates a water treatment and distribution system consisting of fifteen pump stations to service the greater Fairbanks area. Approximately 99% of city residents use the public water system. Groundwater is extracted from public water wells, which are regulated under the auspices of the ADEC's Wellhead Protection Program. Ten USA Wellhead Protection

Area (WHPA) Drinking Water HCAs have been identified in the region of interest. These HCAs are represented on Figure 2 by light blue (cyan) circles with a radius of approximately 0.4 miles.

Adverse effects to the Fairbanks USA WHPA Drinking Water HCAs would result from contamination of the wellheads by a product release.

Chena/Tanana River Commercially Navigable Waterway HCA

Fairbanks is located on the banks of the Chena River. Since goods are transported into Fairbanks via air, truck, and railroad, there is little commercial boat traffic on the river. Commercial traffic is limited to vessels ferrying tourists along the waterway.

The Chena River flows into the Tanana River, a tributary to the Yukon River, which eventually empties into the Bering Sea at the Yukon-Kuskokwim Delta. Fairbanks is located more than 1,000 miles from the mouth of the Yukon River.

Adverse effects to the Chena/Tanana River CNW HCA from a pipeline spill would consist of, among other things, toxic effects on boat traffic from a vapor cloud generated as volatiles are released from the spilled product; possible fire danger to boat traffic from an ignited product release; and the interruption of commercial navigation schedules as a result of spill response activities.

Ecological USA HCAs

An ecologically important community of a small bird species - the olive-sided flycatcher - has been identified within the boundary of the City of Fairbanks. The State of Alaska recognizes the flycatcher as a Species of Concern. This is defined as a species native to Alaska that has entered a long term decline in abundance, or is vulnerable to a significant decline due to low numbers, restricted distribution, dependence on limited habitat resources, or is sensitive to environmental disturbance. The area of concern for this species is its breeding range. The nesting habitat of the olive-sided flycatcher has been delineated and an appropriate buffer around the critical habitat has been established. The buffer is presented as a green circle with a radius of one mile on Figure 2.

A number of rare plant species are also known to exist in the Fairbanks area. These species include Bebb Sedge, Annual Indian Paintbrush, White-tinged Sedge, Crawford Sedge, and Siberian Wormwood.

Adverse effects to the Fairbanks area Ecological USA HCAs from a pipeline spill would consist of, among other things, toxic effects on Species of Concern from a vapor cloud generated as volatiles are released from the spilled product; disruption of breeding activities of Species of Concern; toxic effects from soiling of rare plant species; and possible fire-induced lethality of species from an ignited product release.

Additional HCAs Downstream from Fairbanks That Could Be Affected By a Pipeline Spill

A spill traveling down the Chena, Tanana, and Yukon Rivers could adversely affect a number of identified downstream HCAs. These additional downstream HCAs are summarized below along with their downstream distances from Fairbanks.

Table 3   HCAs Downstream from Fairbanks

HCA	Distance
Ester OPA HCA and USA DW HCA	12 miles
Nenana OPA HCA and USA DW HCA	63 miles
Manley Hot Springs OPA HCA and USA DW HCA	155 miles
Tanana OPA HCA	214 miles
Ruby OPA HCA and USA DW HCA	333 miles
Galena OPA HCA	379 miles
Koyukuk OPA HCA	415 miles
Nulato OPA HCA	429 miles
Kaltag OPA HCA and USA DW HCA	464 miles
Grayling OPA HCA and USA DW HCA	590 miles
Anvik OPA HCA and USA DW HCA	606 miles
Holy Cross OPA HCA and USA DW HCA	642 miles
Russian Mission OPA HCA	723 miles
Marshall OPA HCA and USA DW HCA	783 miles
Pilot Station OPA HCA and USA DW HCA	821 miles
St. Mary's OPA HCA and USA DW HCA	842 miles
Mt. Village OPA HCA and USA DW HCA	857 miles
Emmonak OPA HCA and USA DW HCA	925 miles
Alakanuk OPA HCA and USA DW HCA	930 miles
Sheldon Point OPA HCA and USA DW HCA	940 miles

6.2.4 Fairbanks Example Spill Scenario and Surface Water Transport Analyses

The following example spill scenarios and surface water transport analysis is meant to represent one that might be developed and performed by the operator of the hypothetical Fairbanks pipeline. Following the example is a brief discussion of how the surface water transport analysis approach could be used in an evaluation of the analysis. As for the McGrath examples, readers should keep in mind that the pipeline facilities and spill scenario descriptions are purely hypothetical. Additionally, readers should keep in mind that no actual analysis has been performed for the example. The analysis results presented are felt to be reasonable and are based on the experience of the authors.

Fairbanks Spill Scenario and Surface Water Transport Analysis

Bank erosion along the Chena River is associated with boat wakes generated by recreational watercraft and presents a concern for facilities along the banks of the river. For this analysis, it is assumed that bank erosion and migration caused by boat wakes has proceeded to the point that the buried pipeline is exposed. During a flood event in the early summer, the pipeline is further exposed and becomes damaged by debris floating down the river. The size of the leak, however, is below the operator's SCADA detection limits and, consequently, was not detected until late in the summer when a sheen was noticed on the surface of the water.

The surface water transport analysis was set up with the following assumptions:

- The flow rate from the damaged pipe is approximately 0.1 gallons per minute. The spill persists for 50 days before it is detected, resulting in a total spill volume of 7,200 gallons.
- Transport is during normal summer flow conditions.

A flow measurement is made from the University Avenue Bridge in the late summer. A flow of 235 cubic feet per second is measured with an average cross-sectional velocity of 1.5 feet per second.

Using the field data, a zone of influence screening analysis is performed. Based on the analysis results, it is determined that the only HCA that could be adversely affected by a spill is the Chena/Tanana River CNW HCA. Potential adverse effects to this HCA would consist of toxic effects on boat traffic from a vapor cloud generated as volatiles are released from the spilled product; possible fire danger to boat traffic from an ignited product release; and the interruption of commercial navigation schedules as a result of spill response activities.

A surface water transport analysis is then performed. It is determined that spill concentrations are too low to adversely affect the Chena/Tanana River HCA. No mitigative measures are planned other than periodic stream bank inspection near the pipeline.

Using the Surface Water Transport Analysis Approach

Step 1 (from Plate 2): The Risk Scenario Combination used by the operator is No. 4 - a minor leak resulting from a hydrologic cause. Because the pipeline failure was the result of damage during flooding, however, the operator should probably be required to rerun his zone of influence screening and surface water transport analyses to include overbank spill spreading and transport during 100-year flood conditions.

The operator's analysis, however, has value in that it adequately shows that, during mean flow conditions during which the minor leak is assumed to persist, no adverse effects occur. This is an important factor in determining the risk of minor leaks which can persist for long periods of time prior to detection and, therefore, potentially produce large spill volumes.

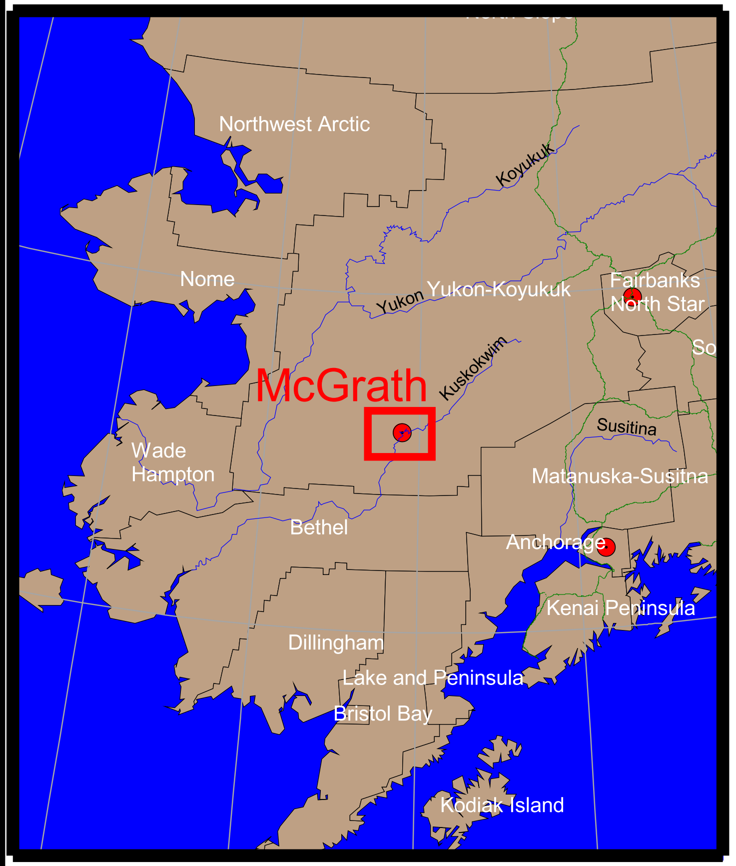
Step 2 (from Plate 3): The spill transport situations to be analyzed should include the floodplain as well as the active channel. The operator's analysis is not consistent with the requirements for use of the 100-year flood. The appropriate spill transport methodologies to use are open water methodologies for the active channel and floodplain. The operator's analysis is not consistent with the requirements for use of the 100-year flood. The operator needs to include overbank flow within the floodplain in his analysis.

Step 3 (from Plate 4): The operator's original zone of influence screening analysis assumed that the spill was restricted to the active channel. The operator's analysis is not consistent with the requirements for use of the 100-year flood. The operator needs to be rerun the screening analysis to include HCAs that could be affected as a result of overbank spreading of the spill during 100-year flood conditions.

Step 4A (from Plate 5): The operator's original analysis used Hydrologic Scenarios/Conditions No. 1 but additional analyses should be run for 100-year flood conditions.

Conclusions Based on Use of the Surface Water Transport Analysis Approach: The operator's original analysis is adequate and appropriate for determining the effects of a persistent minor leak during mean flow conditions. The operator should also be required to analyze the condition of spill spreading and transport during 100-year flood conditions in order to determine whether there could be adverse effects on HCAs located within the floodplain of the river.

TTO Number 3: Surface Hydrology Analysis
Example Scenario I. Rural - McGrath, Alaska



Topographic datasets were compiled from Alaska USGS 15 minute quadrangles. HCA datasets were provided by the USDOT's National Pipeline Mapping System.

Pipeline
Kuskokwim River CNW HCA
McGrath Drinking Water HCA
McGrath OPA HCA

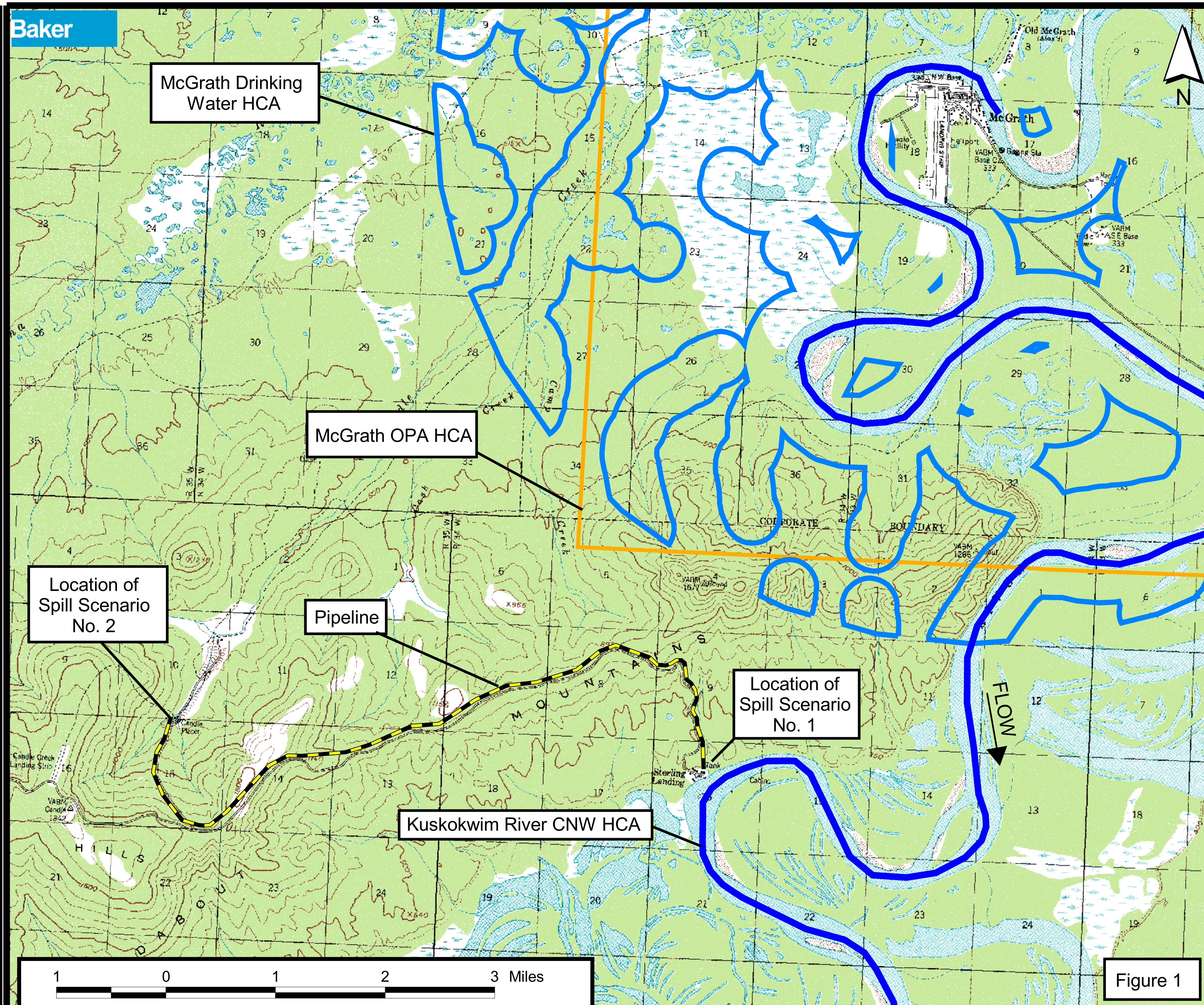
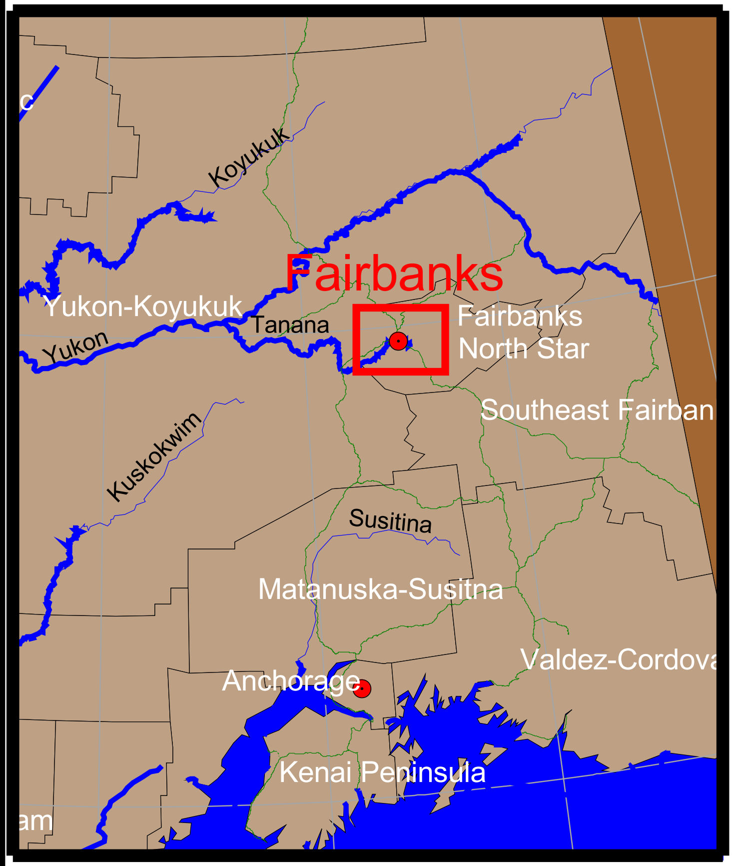


Figure 1

TTO Number 3: Surface Hydrology Analysis
Example Scenario II. Urban - Fairbanks, Alaska



Topographic datasets were compiled from Alaska USGS 15 minute quadrangles. HCA datasets were provided by the USDOT's National Pipeline Mapping System.

Pipeline
Ecological USA HCA
WHPA Drinking Water HCA
Chena Tanana CNW HCA
Fairbanks HPA HCA

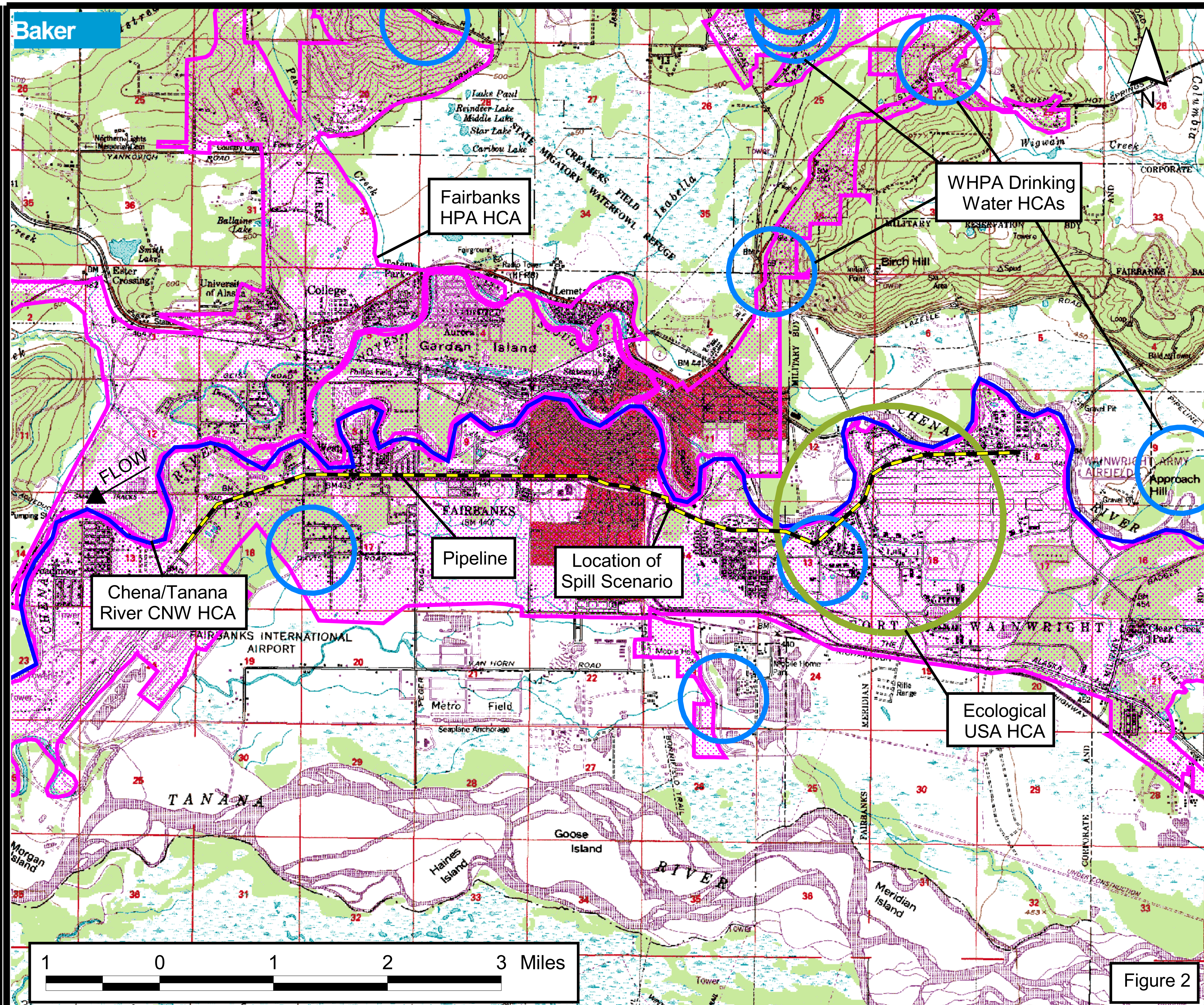


Figure 2

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Appendix A Inland Waterborne Spill Migration: What Factors Must be Considered?

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June 19, 2002

Inland Waterborne Spill Migration: What Factors Must Be Considered?

Objective

From January 04, 2002 to April 19, 2002**,** five OPS teams consisting of two engineers and one Cycla Corporation support staff member performed the Integrity Management Program (IMP) evaluations of 40 large hazardous operators. OPS's audits revealed a smorgasbord of buffer zones in commercially navigable waterways and creeks, brooks, streams, and non navigable rivers. Summarily, OPS discovered that 14 operators did not explicitly consider waterway transport of product releases. Some operators calculated that products released will not be transported more than one mile downstream; another considered a 30-mile downstream buffer.

Because of these variances and to achieve consistency in programmatic reviews, OPS drafted these guidelines to aid staff in their analyses of various IMP plans, specifically as it relates to waterborne transport of oil and refined products. By virtue of this guidance material and supplementary template, OPS will also be able to consistently enforce inadequacies as they are discovered for the waterway transport of product releases. Last, if due credence is given to these factors, OPS's review of plan amendments can be consistently examined.

Background

When oil is released, it spreads very rapidly unless it is contained by something (like a boom or a boat slip in a harbor). The lighter - less dense - the oil, the faster it spreads out to form a very thin sheen. For example, gasoline spreads faster than a heavy black oil, such as No. 6 fuel oils. Faster currents and winds can make oil spread faster. Temperature can sometimes make a difference in how fast an oil spreads in water. Colder oil is less viscous and spreads more slowly. If oil gets cold enough, however, it does not flow like a fluid anymore, but acts more like a solid. This is particularly significant when oil spills occur in arctic areas.

When considering the movement and spreading of oil in lakes, rivers, and streams, it is important to understand the general characteristics of the physical environment, pipeline geometry, ancillary appurtenances, leak detection capabilities, the type of oil and its properties. The factors that play a role in the physical environment are stream flow rates - velocities and discharges, basin shapes, wind patterns, temperature of water, density of surface and submarine vegetation, and salinity of the water. The characteristics of the pipeline that are important in quantifying the amount of potential product releases are its diameter, throughput, gradient, location and number of check valves, type of block valves (manually or remotely actuated), SCADA and leak detection capabilities - proximity of responders, and staff and dispatcher training. Third, the physical and chemical properties of the medium released are just as important because these attributes determine if the product floats, sinks, or mixes with the water. These qualities are density, specific gravity (a non dimensional description of density), viscosity, pour point (particularly useful information in colder climates), flash point, and emulsification.

It is traditionally believed that transport processes in inland waters are less complicated than those encountered in oceans. Inland waters - brooks, creeks, streams, and rivers - generally flow in one direction and in most cases this water is used as a primary resource for potable water and threats to the water supply are a public health problem. Beyond drinking water supplies, power-plant intakes use water as a coolant and industrial processing intakes are often threatened by the potential degradation of water quality. For most inland water spills the shoreline is threatened with pollution almost immediately. When a spill occurs in inland waters there are a number of technical issues that need to be considered:

1) Predicting the travel time of the leading edge of the pollutant plume and the duration of the plume's passage for points (typically water intakes) along rivers and lake shores;
2) Identifying shoreline areas where oil is likely to strand and accumulate; and
3) Estimating the residence time for objectionable concentrations of floating or suspended oil in high-use areas.

Article Structure

Most engineers are fundamentally sound in aspects of pipeline physical characteristics in the evaluation of spill volumes that may be released from pipelines. Therefore, this document has been structured to focus and evaluate the physical environment, oil type and its properties in the analyses of spill migration. At the end of the text is a rudimentary computation for determining the worst-case oil discharge. This document concludes with a tabulated summary identifying the discussed factors, their impact on the distance that a spill may be transported in a waterway, and its significance on the environment. Immediately after this table is a pictorial depiction for each of these variables in a risk-significance matrix.

Until now the impact and significance of each of the variables discussed was explained; however, in numerous instances the effect of a low impact or low significance environmental condition on a low impact or low significance oil type or oil property can spell disaster. Therefore, a reasonable plan should consider the effects of factors in concert with one another. For example, a variable's effect on the distance an oil spill may migrate may be small; however, in concert with other variables the discharged products can pose a significant hazard and the distance it may migrate can be significant. So, this article concludes by briefly describing some case histories - 12 domestic and three international pipeline accidents - to better demonstrate the interaction between the factors identified in the first part of the article and the severity of waterborne transport of hazardous liquid spills.

THE PHYSICAL ENVIRONMENT

Oil Spills in Channels: **Why Does it Differ from Flow in the Open Ocean?**

Flow channels can be described as gullies, brooks, creeks, streams, rivulets, rills, branches, runs, watercourses, tributaries, feeders, freshets, and rivers. Flow channels do not have to be perennial. In many regions in the West, there are pipelines crossing under numerous flow paths that are seasonal - no water flows through it in the summer and autumn seasons but can be a significant source of rapidly flowing water in spring. Furthermore, many of these channels may experience, in the drier months, significant flash floods because of heavy downpours. Some flash floods can significantly erode the soil cover over buried facilities, causing hazardous conditions. For example, during flash floods the water travels at significant velocities and carries sediment and debris which may impact the pipeline. Here are four reasons why oil spills in rivers differ from spills that occur in the open ocean:

1) Some oils are denser than river water - Oil usually floats because it is less dense than the water it is floating on. (Density is the mass, or weight, of a substance divided by its volume.) The density of river water is usually about 1 g/cc. Water in the open ocean is more dense (usually around 1.02 to 1.03 g/cc) because it contains more salt; the higher the salinity of water, the more dense it is.

   Densities of oils range from 0.85 g/cc for a very light oil (like gasoline) to 1.04 g/cc (for a very heavy oil). Most types of oils have densities between about 0.90 and 0.98 g/cc. These oils will float in either the river or the ocean. But very heavy oils, which have a density greater than 1.0 g/cc, would float in the ocean, but sink in a river. Sometimes the density of an oil is so close to that of river water that the oil moves along the river partly underwater. Oil and water at about the same density pose problems in the capture and subsequent clean up activities. When oil floats just below the surface, conventional booms may be unable to secure the product discharged and therefore be unable to fulfill its intended purpose.

2) Movement is usually downstream - Unlike in a bay or the open ocean, currents in a river are generally directed downstream (except very close to the mouth of the river, where it enters the ocean; here, a flood tide might actually reverse the flow of the surface water). The greater predictability of river currents makes it easier to predict which way the oil will move. Wind blowing across the river also effects where the oil will come ashore. If the wind is blowing straight down the river (as might happen on a river with high banks), it often will travel quite far down the river before it comes in contact with a beach. In order for the oil to beach, the wind must blow the oil to one side of the river or the other.

3) Dams and locks influence oil movement - Rivers sometimes contains dams or locks that slow or divert water flow. Dams and locks also slow down the movement of spilled oil. In fact, oil tends to collect in areas next to dams or locks.

4) Vegetation may grow right at the water's edge - Along many rivers, plants and trees grow right up to the river's edge. Those rivers don't have the open, sandy shores that one finds along the many parts of the open coast. It is much harder to remove oil from vegetation than from a hard-packed sand beach. Spill responders try to protect the plants by using booms, but if the vegetation gets oiled, responders often either cut, burn, or flush it with water to try to get the oil out.

Major Characteristics of a River Stream

A river system consists of a main channel and all of the tributaries that flow into it. Within a river system, the surface of the ground slopes toward the network of tributaries, so the drainage system acts as a funneling mechanism for removing surface runoff and weathered rock debris. A typical river system can be divided into three subsystems:

1) Collecting system (branches) - consists of a network of tributaries in the headwater region, and collects and funnels water and sediment to the main stream
2) Transporting system (trunk) - the main trunk stream functions as a channel way through which water and sediment move from the collecting area toward the ocean. (Erosion and deposition also occur in a river's transporting system)
3) Dispersing system (roots) - consists of a network of distributaries at the mouth of a river (delta), where sediment and water are dispersed into an ocean, a lake, or a dry basin

Concepts Relating to Streams

1) Number of tributaries decreases as you move downstream.
2) Length of tributaries becomes greater downstream.
3) Slope/gradient (how steep it is) of stream channel decreases downstream. The slope is measured in terms of feet per mile (feet/mile).
4) Stream channels become deeper and wider downstream.
5) Size of the valley is proportional to size of the stream and increases downstream.

Flow in Rivers

It is misleading to treat releases in rivers similar to those that occur in oceans and bays because of the fundamental differences in the turbulence levels and current shears typical in rivers. In oceans or large lakes, surface-wave activity is the major source of turbulence. Because of this, turbulence levels typically drops off with depth. This does not apply to the flow in rivers.

In rivers, shear in currents along the river bottom and banks are typically the major source of turbulence. Thus, mixing and dispersions caused by the interaction of the shear and turbulence can move significant amounts of oil below the surface particularly if it is relatively dense like heavy No. 6 fuel-oil or it is finely distributed as droplets. The shear-dominated river regimes tend to produce spill distributions having higher subsurface oil concentrations than would be expected in marine spills.

Shear-dominated flows cause another effect that characterizes river spills. The lower speeds along the banks and bottom of the river indicate that the surface and center of a river move downstream faster than flow along its boundaries. Therefore, mixing will continuously exchange water and pollutants between the slower, near-bank regions and the faster, center regions of the river, with the resulting smearing of the distribution along the axis of the flow.

A second consequence of shear-dominated flow is that although it might be possible to predict the initial arrival of a product at an intake along the river, it will be considerably more difficult to estimate when the threat is past because the slower areas in the river are continually supplying slower moving products that reside at the periphery of the plume to the main stream.

Dynamics of Stream Flow

Rivers are highly complex systems influenced by a number of variables and, as is the case with so many natural systems, if one variable is changed it produces a change in the others. The most important variables are:

1) Discharge - The amount of water passing a given point during a specific time interval; the rate of flow is measured in cubic feet per second (cfs). For example, the Rio Grande's discharge in Laredo is about 3,000 cfs but its discharge in Brownsville is about 80 cfs. How? The Rio Grande essentially becomes an estuary because water is siphoned for human use. Similarly, the discharge of the Mississippi River is about 1,000,000 cfs. In contrast, the discharge of Amazon (world's largest river in terms of water volume) is about several million cfs.

   Although velocities and gradients may vary along a given channel with no tributaries or dams, the discharge rate is constant. Recall that the discharge rate is the amount of water passing a given point in unit time. Boulder Creek is typically about 50 cfs through much of Fall and Winter, but may approach 1,000 cfs during late May and early June. The Colorado at Grand Junction is typically 2,000 cfs during fall and winter but may exceed 20,000 in May and June. The Colorado above Lake Powell and below the Green (Cataract Canyon) is typically 5,000 cfs but may peak above 100,000 cfs in a flood. Typical discharges from Glen Canyon Dam are 8,000 to 12,000 cfs. The Mississippi in the 1993 Flood peaked at more than three million cfs.

2) Stream Velocity - The speed of the flow of water in a river system. The velocity is greatest in the center of a straight channel: curved channels provide highest velocities; narrow/shallow channels have too much friction from surface areas outside of a meander bend where velocity is greatest; the inside of a meander bend is where velocity is lowest. The gradient the slope of the stream channel also influences velocity: the steeper the gradient, the higher the velocity.

The gradient of a stream is steepest in the headwaters and decreases downslope because of sediment loads. For example, the Boulder Creek falls from Nederland at about 8,000 ft to Boulder at 5,600 ft over a distance a distance of 15 miles and thus has a gradient of 160 ft/mi. The Colorado River through Grand Canyon has a gradient of less than 10 ft/mi and the lower Mississippi has a gradient of 0.5 ft/mi. The stream gradient usually decreases downstream as the channel approaches the mouth of the ocean and is usually negligible in the delta.

Stream velocities vary with gradient and channel size. The lower Mississippi typically moves at less than 1 mi/hr. Channel constrictions cause an increase in stream velocity. In the lower parts of the drainage system (transporting and dispersing systems) the gradient of the rivers is very low. So, if all other variables are the same (size, shape, roughness and discharge), steeper gradient streams would have higher velocities.

The factors that control stream velocity are:

i) Gradient - slope along the stream as well as between streams.
ii) Shape - most efficient is the stream with the smallest perimeter for a given cross-sectional area.
iii) Size - an increase in size reduces the perimeter/cross-sectional area ratio.
iv) Roughness - rougher bottoms consisting of boulders and cobble slow stream velocity by disrupting flow and causing turbulence.

Base-Flow Characteristics of Streams

During dry weather periods, flow in natural streams is sustained primarily by groundwater discharging from aquifers into the channels. These dry weather flows, or base flows, typically exhibit the chemical properties of the groundwater. The natural base-flow regime of many streams is significantly altered by reservoirs, weirs, stream intakes, well fields, wastewater treatment plants, and other facilities.

The amount of groundwater contributing to the streamflow varies along the channel and according to the hydraulic gradient in the contributing aquifer. When a stream level is below the bordering groundwater table, a positive gradient exists and groundwater flows into the stream. If the bordering watertable declines below stream level, seepage may flow from the stream into the aquifer. Water that seeps into stream banks during passage of floods is referred to as bank storage and returns relatively quickly to the stream after high flows recede.

Why is this important? We must now revert back to the definition of “could affect” in high consequence areas. If a release occurs during a dry period when the water table declines below stream level, product or chemical components may flow with the water into the aquifer. Now, the extent of a buffer zone is very difficult to apply. Operators will have to drive groundwater monitoring wells to periodically examine the extent of contamination.

Stream Longitudinal Profile

A typical longitudinal profile is curved, with a steep slope near the headwaters, and a gentle slope near the mouth. That means that the stream gradient (average slope of the stream) is greater near the headwaters and less near the mouth. The elevation below which a stream can't cut is called its ultimate base level. In general, the ultimate base level is sea level.

If the base level changes, then the stream starts to modify the landscape to reestablish a standard longitudinal profile. Typically, the gradient decreases downstream and the discharge increases downstream as more and more tributaries contribute to flow. As discharge increases, in order to handle the additional water, either the stream velocity increases or the width and the depth of the channel increases or a combination of both occur as enlarged channels typically have less frictional drag.

Flow Regimes

There are two dominant flow regimes in rivers: laminar and turbulent. Flow in natural channels normally occurs as turbulent, gradually varied flow. Under conditions of gradually-varied flow, the stream’s velocity, cross section, bed slope, and roughness vary from section to section, but the changes occur gradually enough that formulae for steady-uniform flow can be applied in analysis. Steady-uniform flow occurs when conditions at any given point in the channel remain the same over time and velocity of flow along any line of flow remains constant in both magnitude and direction. Whether a flow is laminar or turbulent depends on these three factors:

i) Flow velocity
ii) Channel geometry
iii) Viscosity (a measure of a fluid’s resistance to flow)- The higher the viscosity, the greater the tendency for laminar flow. Water has low viscosity in the common range of temperatures at Earth’s surface.

Moving down gradient from headwaters to mouth the stream gradient and roughness decrease. However, in steep, rough mountainous channels, turbulent flow dominates and may appear faster moving. In contrast, in wide, placid rivers of the lowlands, large discharges and velocities with smooth, laminar flow prevails.

The basic formulae used to analyze flow in natural channels are: (1) the Continuity Equation (2) Bernoulli's Energy Equation, and (3) Manning's Equation. The Continuity Equation expresses one of the fundamental principles of stream flow dynamics. It states that the discharge passing a channel cross section is equal to the cross-sectional area multiplied by the average velocity of flow. Average velocity is used in the equation because velocity is not uniformly distributed in a channel cross section due to boundary shear resistance and other factors. Bernoulli's Energy Equation expresses the relationship between the elevation head, velocity head, and energy dissipation required to move water and sediment. Energy dissipation includes those due to friction and expansion or contraction of flow. Dissipation of energy by friction is determined by applying the Manning Equation. Simultaneous solution of the Continuity Equation, Bernoulli's Energy Equation, and Manning's Equation allows for calculation of water surface profiles and average velocities of flow.

Continuity Equation: $Q = (A).(V)$

where: Q = discharge;
A = cross-sectional area of channel;
V = velocity

Bernoulli's Energy Equation: $(V_1^2/2g) + d_1 + z_1 = (V_2^2/2g) + d_2 + z_2 + h_e$

where: g = gravity constant;
h_e = energy losses (friction losses+expansion and contraction losses)
z = elevation head

Manning's Equation: $Q = (1.5/n).(A).(R^{2/3}).(S^{1/2})$

where: n = Manning's roughness coefficient varies from 0.025 to 0.15;
R= hydraulic radius;
P = wetted perimeter;
S = friction slope

Flood Plains and Storm Events

Some processes that prevail in inland waters are seasonal, like changes in runoff and rainfall. The most evident of these changes are the changes in water levels and increases in river speeds in response to rains. Many rivers have correlation tables that compare the river gauge height to volume discharge. These tables can be used to estimate the average channel velocity. Regional river forecast offices of the National Weather Service or Army Corps of Engineers operations are a good place to obtain such information.

Changes in the water levels can be very important in inland water bodies that have manmade flood controls upstream or downstream of pipelines. Water level changes frequently alters the nature of the drainage system. In arid regions of the West, catchment dams form large lakes during periods of abundant rainfall, which usually return to rivers during droughts. Parts of Lake Shasta in California and some of the catchment systems on the upper Missouri River are good examples of this.

At the other extreme, when discharge rates are high, some lock and dam systems behave like a river with a series of waterfalls. However, they may end up more like a series of slightly connected lakes when the flow drops off. Sections of the Ohio and Mississippi rivers are good examples of this situation. Under these circumstances, historical data collected under alternate flow conditions may be misleading. Special care must be taken when developing estimates of movement and arrival times.

Floods, most likely, are the most extreme form of water level change and introduces an entirely new set of problems. Some waterways are completely diverted from their previous flow paths. It is also possible that flood conditions may threaten above the surface and subsurface riverside facilities, infrastructure, and structures.

A flood plain is the area adjacent to a river, creek, lake, stream, or other open waterway that is subject to flooding when there is significant rain. Frequently in Spring the amount of runoff is supplemented by melting snows in colder climates.

Usually zoning maps and State Departments of Environmental Protection, or similar, show 100-year flood plains and 25-year flood plains. In a 100-year flood plain there is a 1-in-100 chance that in any given year the area within that flood plain will flood. Similarly, in a 25-year flood plain there is a 1-in-25 chance that in any given year that area will flood. The statistical chance of flooding is not changed by any one flooding event; but repeated flooding may result in the flood plain being recalculated. A 100-year flood plain is always wider than a 25-year flood plain, and the 25-year flood plain is contained within the 100-year flood plain.

The above reasoning also applies to storm events. A 25-year storm event is a storm whose intensity is seen, on average, once in 25 years. This does not mean that once every 25 years there will be a storm of this intensity. In fact, there could be a much greater time interval between such storms, or they could occur in consecutive years.

A 100-year storm event is a storm whose intensity is seen, on average, once in 100 years. Again, this does not mean that once every 100 years there will be a storm of this intensity. In fact, there could be a much greater time interval between such storms, or they could occur in consecutive years.

The amount of precipitation during these statistical storm events is based on the average interval between such storms and over a large number of years. Most developers use the 25-year storm event in their planning process. If the engineered structure can accommodate a 25-year storm event, it is considered an adequate design. Structures such as dams and other facilities close to densely populated areas or those with the potential of generating tremendous damage to the regional environment and ecology are usually designed to withstand 100-year storm events.

A 100-year storm does not always cause a 100-year flood. Several factors can independently influence the cause-and-effect relation between rainfall and stream flow. When rainfall data are collected at a point within a stream basin, it is highly unlikely that this same amount of rainfall occurred uniformly throughout the entire basin. During intensely localized storms, rainfall amounts throughout the basin can differ greatly from the rainfall amount measured at the location of the rain gauge. Some parts of the basin may even remain dry, supplying no additional runoff to the stream flow and lessening the impact of the storm. Consequently, only part of the basin may experience a 100-year rainfall event.

Existing conditions prior to the storm can influence the amount of storm water runoff into the stream system. Dry soil allows greater infiltration of rainfall and reduces the amount of runoff entering the stream. Conversely, soil that is already wet from previous rains has a lower capacity for infiltration, allowing more runoff to enter the stream.

Another factor is the relation between the duration of the storm and the size of the stream basin in which the storm occurs. For example, a 100-year storm of 30-minutes duration in a 1-mi^2 basin will have a more significant effect on stream flow than the same storm in a 50-mi^2 basin. Generally, streams with larger drainage areas require storms of longer duration for a significant increase in stream flow to occur. These and other factors determine whether or not a 100-year storm will produce a 100-year flood.

OIL TYPES AND PROPERTIES

Crude oil is a liquid component of petroleum, which also exists as petroleum gases such as propane and butane, and in a number of solid forms such as asphalt and bitumen. Any of these states can coexist, depending on chemical processes. The non hydrocarbon fraction of crude oil is made up mostly of organic compounds that contain nitrogen, sulfur, oxygen, and heavy metals such as nickel and vanadium.

These non hydrocarbonated impurities are used as descriptors of oil composition, such as "sour" as applied to crude oil having a high sulfur content. For example, Louisiana crude is considered as "sweet". The non hydrocarbonated fraction of oil is an important ingredient in emulsification, in which large quantities of water droplets can be incorporated into spilled oil to form emulsions composed of mostly small water droplets. Under certain chemical and turbulent energy conditions, this phenomenon can result in the formation of "chocolate mousse", a very viscous fluid having significantly different physical properties than those of the parent oil. Last, the non-hydrocarbonated fraction is generally more soluble and often more toxic than the hydrocarbon fractions. This is particularly important for freshwater spills where dilution capacity might be restricted and dispersion into the water column could affect drinking and industrial water supplies.

The petroleum industry often characterizes crude oils according to their geographical source, e.g., Alaska North Slope Crude. Oils from different geographical areas have unique properties; they can vary in consistency from a light volatile fluid to a semisolid. Classification of crude oil types by geographical source is generally not a useful classification scheme for response personnel because they offer little information about general toxicity, physical state, and changes that occur with time and weathering. These characteristics are primary considerations in oil spill response. The classification scheme provided below is more useful in a response scenario.

<u>Class A - Light, Volatile Oils</u>: These oils are highly fluid, often clear, spread rapidly on solid or water surfaces, have a strong odor, a high evaporation rate, and are usually flammable. They penetrate porous surfaces such as dirt and sand, and may be persistent in such a matrix. They do not tend to adhere to surfaces; flushing with water generally removes it. Class A oils may be highly toxic to humans, fish, and other biota. Most refined products and many of the highest quality light crudes can be included in this class.

<u>Class B - Non-Sticky Oils</u>: These oils have a waxy or oily feel. Class B oils are less toxic and adhere more firmly to surfaces than Class A oils, although they can be removed from surfaces by vigorous flushing. As temperatures rise, their tendency to penetrate porous substrates increases and they can be persistent. Evaporation of the volatile components may lead to a Class C or D residue. Medium to heavy paraffin-based oils fall into this class.

<u>Class C - Heavy, Sticky Oils</u>: Class C oils are characteristically viscous, sticky or tarry, and brown or black. Flushing with water will not readily remove this material from surfaces, but the oil does not readily penetrate porous surfaces. The density of Class C oils may be near that of

water and they often sink. Weathering or the evaporation of the volatile constituents may produce solid or tarry Class D oil. Toxicity is low, but wildlife can be smothered or drowned when contaminated. This class includes residual fuel oils and medium to heavy crudes.

Class D - Nonfluid Oils: Class D oils are relatively non-toxic, do not penetrate porous substrates, and are usually black or dark brown in color. When heated, Class D oils may melt and coat surfaces making clean up very difficult. Residual oils, heavy crude oils, some high paraffin oils, and some weathered oils fall into this class.

These classifications are dynamic for spilled oils; weather conditions and water temperature greatly influence the behavior of oil and refined petroleum products in the environment. For example, as volatiles evaporate from a Class B oil, it may become a Class C oil. If a significant temperature drop occurs (e.g., at night), a Class C oil may solidify and resemble a Class D oil. Upon warming, the Class D oil may revert back to a Class C oil.

Refined petroleum products are derived from crude oils through processes such as catalytic cracking and fractional distillation. These products have physical and chemical characteristics that differ according to the type of crude oil and subsequent refining processes. Several examples of refined petroleum products and their properties include:

Gasoline is a lightweight material that flows easily, spreads quickly, and may evaporate completely in a few hours under temperate conditions. It poses a risk of fire and explosion because of its high volatility and flammability, and is more toxic than crude oil. Gasoline is amenable to biodegradation, but the use of dispersants is not appropriate unless the vapors pose a significant human health or safety hazard.

Kerosene is a lightweight material that flows easily, spreads rapidly, and evaporates quickly. Kerosene is easily dispersed, but is also relatively persistent in the environment.

No. 2 Fuel Oil is a lightweight material that flows easily, spreads quickly, and is easily dispersed. This fuel oil is neither volatile nor likely to form emulsions, and is relatively non-persistent in the environment. No. 4 Fuel Oil, a medium weight material that flows easily, and is easily dispersed if treated promptly. This fuel oil has a low volatility and moderate flash point, and is fairly persistent in the environment.

No. 5 Fuel Oil (Bunker B) is a medium weight to heavyweight material with a low volatility and moderate flash point. Preheating may be necessary in cold climates, and this fuel oil is difficult, if not impossible, to disperse.

No. 6 Fuel Oil (Bunker C) is a heavyweight material that is difficult to pump and requires preheating for use. This fuel oil may be heavier than water, is not likely to dissolve, is difficult or impossible to disperse, and is likely to form tar balls, lumps, and emulsions. It has a low volatility and moderate flash point. No. 6 fuel oil is usually heated for transport through pipelines because of its viscosity.

Lubricating Oil is a medium weight material that flows easily and is easily dispersed if treated promptly. This oil has a low volatility and moderate flash point, but is fairly persistent in the environment. Lubricating oil is seldom transported through pipelines over long distances.
Specific Gravity - The specific gravity of most crude and refined oils lies between 0.78 and 1.0, which means that they usually float in water.

Viscosity is an important physical property because, along with density, it helps determine the oil's behavior during a spill. The viscosity determines the spreading rate of oil slicks; it controls the stability of emulsions, because water droplets cannot escape from viscous oils and are difficult to skim and pump. It may also affect evaporation rates of the volatile fractions.

As in the case of oil density, oil viscosity also increases with decreasing temperatures. The relative change with temperature depends on the oil and increases with an oil's paraffin content. Viscosity also increases as the oil is aged by evaporation of the lighter components and by photochemical and microbial processes.

Pour Point is the temperature below which an oil cannot be poured. This is useful in colder climates where knowing if the oil is fluid enough to be pumped without special heating equipment is important. The pour point temperature also affects cleanup and salvage operations.

Flash Point of combustible liquids is defined as the lowest temperature at which the vapor/air mixture will ignite. The flash point of combustible liquids is inversely proportional to its equilibrium vapor pressure. The lower the flash point, the greater the hazard.

Emulsification is the least understood of the oil properties but is known to be proportional to the intensity of water turbulence and once started, proceeds rapidly. Not only does emulsification change the physical properties of the material in a slick, but may also increase the volume of the material to be captured.

Hydrogen Sulfide (H_2S) evolves during distillation and other heating processes. H_2S is a toxic gas with a time-weighted average exposure limit of 10 parts per million (ppm) and a short term exposure limit of 15 ppm.

Surface Tension controls the rate at which the oil will spread. Oils with a low surface tension will spread more rapidly so that a greater surface area is exposed to weathering. Surface tension is partially controlled by ambient temperatures and decreases as temperatures increase.

SPILL DYNAMICS AND A SIMPLE COMPUTATION FOR A WORST-CASE SPILL SCENARIO

The computation of the volume discharged in the event of a spill is important because clean up plans must be implemented for the maximum spill exposure at the specific high risk location. Spill studies also prepare the company to plan for emergencies even though the probability of ever having an emergency is very low.

A spill from a pipeline consists of three components: (1) The volume discharged before the event is detected in the control room; (2) The volume discharged during the shut down phase; and (3) The volume discharged from drainage after all pressures have been reduced to essentially zero psig.

In the case of the first component, considerable product can be discharged before any significant change in pressure or flow rate is detected by instruments usually located several miles from the leak location. The second component is the result of the compressibility as the product pressure is reduced to zero psig in the pipeline section between block valves during shut down following a pipeline rupture. This includes the volume discharge that can be attributed to response time of the equipment. The third component is the volume discharged by gravity after shut down is realized. The flow rates that may be attributed to this component is usually lower because the pressures driving its flow is much lower. The volume discharged is dependent on elevation differences and product properties.

For a pipeline facility, the size of the worst case discharge scenario is the volume possible from a pipeline break. This volume can be calculated as follows:

1) Add the pipeline system leak detection time to the shutdown response time.
2) Multiply the time calculated in (1) by the highest measured oil flow rate over the preceding 12-month period. For pipelines recently put in service, use the predicted oil flow rate in the calculation.
3) Add to the volume calculated in (2) to the total volume of oil that would leak from the pipeline after it is shut in. Calculate this volume by taking into account the effects of location of break, hydrostatic pressure, gravity, pipeline gradient, frictional wall forces, length of the pipeline segment, tie-ins with other pipelines, reverse flow from laterals, drain-down, and other factors.

History has demonstrated that besides considering only pipeline operating history, cognizance of dispatcher, training and work performance, it is also prudent to include at least one pump restart and the subsequent volume of the product injected into the pipeline in the above calculations.

SUMMARY OF FACTORS TO BE CONSIDERED AND THEIR IMPORTANCE

Factor	Impact	Significance
Physical Environment		
Stream Discharge Rate	High	Severe
Stream Velocity	High	Severe
Base Flow Characteristics	High	Moderate
Stream Longitudinal Profile	High	Severe
Stream Lateral Profile	High	Severe
Water Viscosity	Low	Low
Laminar Flow Regime	Low	Moderate
Turbulent Flow Regime	High	Severe
25-Year Storm Event	High	Severe
100-Year Storm Event	High	Severe
Oil Type		
Crude Oils		
Light, Volatile Oils	High	Severe
Non-Sticky Oils	Low	Moderate
Heavy, Sticky Oils	Low	Low
Class D Oil	Low	Moderate
Class D Non-fluid Oils	Low	Low
Refined Products		
Gasoline	High	Severe
Kerosene	High	Severe
No. 2 Fuel Oils	High	Moderate
No. 5 Fuel Oils	Low	Low
No. 6 Fuel Oils	Low	Low

Lubricating Oils	Low	Low

SUMMARY OF FACTORS TO BE CONSIDERED AND THEIR IMPORTANCE

Factor	**Impact**	**Significance**
Oil Properties		
Specific Gravity	High	Severe
Viscosity	High	Moderate
Pour Point	Low	Low
Flash Point	Low	Severe
Emulsification	Low	Low
H_2S-content	High	Severe
Surface Tension	Low	Moderate

PHYSICAL ENVIRONMENT

IMPACT		LOW	MODERATE	SEVERE
	HIGH		Base Flow Characteristics	Stream Discharge Rate Stream Velocity Stream Longitudinal Profile Stream Lateral Profile Turbulent Flow Regime 25-Year Storm Event 100-Year Storm Event
	LOW	Water Viscosity	Laminar Flow Regime	
		SIGNIFICANCE		

OIL TYPES

IMPACT		LOW	MODERATE	SEVERE
	HIGH		No. 2 Fuel Oils	Light Volatile Oil Gasoline Kerosene
	LOW	Heavy Sticky Oil Class-D Non-Fluid Oil No. 5 Fuel Oils No. 6 Fuel Oils Lubricating Oils	Non-Sticky Oil Class-D Oil	
		SIGNIFICANCE		

OIL PROPERTIES

IMPACT		LOW	MODERATE	SEVERE
	HIGH		Viscosity	Specific Gravity H_2S-content
	LOW	Emulsification Pour Point	Surface Tension	Flash Point
		SIGNIFICANCE		

BRIEF CASE HISTORIES

The distance a plume of oil migrates can be significant based not only on the volume spilled, but also other contributing factors from the physical environment. Furthermore, the time it takes to detect a pipeline spill can have a significant impact on its migration before a sufficient attempt is made for its containment. These brief case studies try to demonstrate that even in very placid environments, spills can become an environmental disaster and impact communities farther downstream.

This begs these questions: Can a high consequence area be limited to the buffer zones proposed by pipeline operators in their Integrity Management Plans? What combination of factors can the Operator propose to justify their buffer zones? For spills in extremely small buffer zones, within what time interval can the Operator leak detection system notify them? Does the Operator's spill response plans contain special equipment or response actions to justify such small buffer zones.

There have been numerous other spills that occurred overland but eventually products reached farm and drain tiles, and storm water inlets. These conduits conveyed spilled products into outlets located in streams which then transported them into larger water bodies. The volume of product that can reach these conduits is compounded when the terrain over which the product flows is paved or thickly iced over. Case histories of such events were not included in this section.

Another question that readers may ask: Why have incidents that did not occur in the United States be included in this section? The likelihood of disastrous spills is not unique to the USA although significant amounts of oil and refined products are transported across our nation. Second, it is important to demonstrate the environmental impacts of large oil spills. Third, even with one of the most mature containment strategies and incident command management systems, factors other than monies spent on containment can have a significant influence although the discharge may be considered moderate.

It is evident from the case histories below that the Colonial Pipeline Company's spill in Tennessee, the Potomac Electric Power Company's (PEPCO) spill in Maryland, the Olympic Pipeline release in Washington, and the Amoco Pipeline Company unintended discharge in Missouri were relatively moderate. However, the oil slick in Tennessee migrated for some six miles downstream of the rupture. PEPCO's spill was virtually contained until the emergence of a moderate storm system that forced the product over and under the booms and eventually devastated a vast area in the Patuxent River. Third, besides flowing for some 1.5 miles in the Whatcom Creek, the fire that ensued after the Olympic Pipeline release burned 25 acres of habitat and decommissioned the City's water supply for about four months. Last, during a routine purging and decommissioning operation, Amoco Pipeline Company experienced a release of some 100,000 gallons of oil in a field that fouled about 45 miles of rivers and streams leading to the Missouri River.

Three case histories - Explorer Pipeline Company, the San Jacinto River flood, and one reported by Petrobras, Brazil - show the effect of severe weather (flash floods, 100-year storm events, and persistent rainfall) and the difficulties of containment. In the Colonial Pipeline Company accident near Locust Grove in 1989, three factors - ice, rapid thaw, and rain - compounded the problem. In the remaining seven accidents - five domestic and two international - there were no aggravating factors; however, the waterways conveyed the spills significant distances from the rupture location and contaminated banks and coast lines and disrupted community drinking water resources.

1) Potomac Electric Power Company Oil Spill on April 07, 2000

On April 07, 2000, a 12-inch diameter pipeline ruptured in the Swanson Creek, a tributary of the Patuxent River, in Maryland. About 123,000 gallons of a mixture of No. 6 and No. 2 fuel oils was discharged into the waterway. The Swanson Creek is a tranquil creek and being a heavy oil that was discharged, it did not migrate too far. But on April 08, the weather patterns changed. The noreaster raised the tide very high. As the wind shifted to the northwest, it pushed oil over the boom. What happened next is a classic worst-case scenario. The storm with 50-knot northwest winds descended on the area and swept the oil over the booms and drove the oil a mile across and several miles downriver and affected a 17-mile stretch of the Patuxent River and shoreline.

2) Explorer Pipeline Company Release on March 09, 2000

On March 09, 2000, a 28-inch diameter pipeline ruptured and released about 564,000 gallons of gasoline near Greenville, Texas. The release occurred on land; however, it flowed across the surrounding terrain into a dry creek bed and then into the East Caddo Creek. The next morning it rained heavily; an estimated 1.5 to 2 inches of rain fell in the area, and East Caddo Creek rose about 12 feet. The leading edge of the gasoline was stopped about 15 miles from the rupture site and about seven miles upstream of Lake Tawakoni, a major water supply for the Dallas-Fort Worth metropolitan area and smaller neighboring communities. After the accident, methyl tertiary butyl ether, a component of the gasoline, was discovered in Lake Tawakoni.

3) Olympic Pipeline Company Release on June 10, 1999

On June 10, 1999, a 16-inch diameter pipeline ruptured and subsequently released about 236,800 gallons of unleaded regular gasoline into a creek that flowed through the Whatcom Falls Park in Bellingham, Washington. The released product flowed below the surface for some distance and exited the surface near Hannah Creek after which it flowed into the Whatcom Creek. Nearly one and one-half hours after the rupture, gasoline vapors along the Hannah and Whatcom creeks ignited and dent flames approximately one and one-half mile downstream of the pipeline rupture. By the time the fire was extinguished about five days later it had burned about 25 acres of habitat. The City of Bellingham's water supply was restored on October 07.

4) Williams Pipeline Release on May 10, 1999

On May 10, 1999, a 16-inch diameter pipeline spilled more than 210,000 gallons of fuel oil into Independence Creek in Atchison County, Kansas. The oil reached the Missouri River and a sheen was observed as far downstream as Leavenworth, Kansas, about 20 miles from the rupture location.

5) Colonial Pipeline Company Release on February 09, 1999

On February 09, 1999, a 10-inch diameter pipeline ruptured in East Knoxville and released about 54,000 gallons of high sulfur diesel fuel near Goose Creek in Knoxville, Tennessee. The leading edge of the oil slick advanced about six miles downstream on the Tennessee River from Goose Creek. For the next several days the Tennessee River in the Knoxville area was closed to navigation.

6) Colonial Pipeline Company Release on June 26, 1996

On June 26, 1996, a 36-inch diameter pipeline ruptured at the crossing with the Reedy River at Fork shoals, South Carolina. About 958,000 gallons of fuel oil was discharged into the Reedy River and surrounding areas. The released fuel oil traveled about 22 miles downstream in the Reedy River.

7) San Jacinto River Flood between October 14 and October 21, 1994

In mid-October 1994, some 15 to 20 inches of rainfall resulted in major flooding occurred in the San Jacinto River flood plain near Houston, Texas. Due to the flooding, eight pipelines ruptured and 29 others were undermined at river crossings and the new channels created in the flood plain. More than 1.47 million gallons of petroleum and petroleum products were released into the river. Ignition of petroleum and petroleum products from the river resulted in 547 people receiving mostly minor burn and inhalation injuries. The 100-year storm flood was equaled to at one station and exceeded at 18 of the other 43 stations. The San Jacinto River which normally flows at about 2.5 feet above mean sea level crested at 28 feet above mean sea level. The peak discharge was more than 350,000 cfs, about 58 percent greater than the 100-year flood. The highest velocity measured was 16.6 fps - about 11 mph.

8) Colonial Pipeline Company Release on March 28, 1993

On March 28, 1993, a 36-inch diameter pipeline ruptured in Fairfax County, Virginia, and sent more than 400,000 gallons of oil from a parking lot in Reston into the Sugarland Creek. At that time it was one of the largest inland oil spills in history. The oil affected nine miles of the nearby Sugarland Run Creek and the Potomac River and about 48 miles of river banks were contaminated.

9) Colonial Pipeline Company Release on December 19, 1991

On December 19, 1991, a 36-inch diameter pipeline ruptured about three miles northeast of Simpsonville, South Carolina. The rupture allowed more than 500,000 gallons of diesel fuel to flow into the Durbin Creek and caused pollution that affected about 26 miles of waterways, including the Enoree River, which flows through the Sumter National Forest. The spill also forced Clinton and Whitmire, two South Carolina communities, to use alternative water supplies.

10) Amoco Pipeline Company Release on November 05, 1990

On November 05, 1990, a 12-inch diameter pipeline ruptured near Turkey Creek, between Laplata and Freeman near Ethel, Missouri, during a purging and decommissioning operation. The spill occurred in a field near the Chariton River. Despite the effort of workers, equipment, and dams, winds pushed the product down the Chariton River from Turkey Creek. About 45 miles of rivers and streams were fouled by the discharge.

11) Colonial Pipeline Company Release on December 18, 1989

On December 18, 1989, a 32-inch diameter pipeline failed spontaneously in Locust Grove, Unionville, Virginia. About 212,000 gallons of kerosene spilled into the Rapidan and Rappahannock Rivers. Colonial constructed two dams to contain the product. Unfortunately, these efforts were impeded due to the remote location of the spill and to a solid layer of ice that trapped the kerosene underneath. On New Year's eve after a rapid thaw and heavy rains, the containment dams broke and the kerosene flowed toward the City of Fredericksburg, more than 20 miles away from the rupture location. The City's water supply was cut off and drinking water had to be hauled from Stafford County for seven days.

12) Colonial Pipeline Company Release on March 06, 1980

On March 06, 1980, a 32-inch diameter pipeline ruptured in two locations simultaneously. The first rupture occurred near Manassas, Virginia and resulted in the release of about 336,000 gallons of aviation-grade kerosene. The kerosene flowed into the Bull Run river and entered the Occoquan Reservoir, a source of drinking water for several northern Virginia communities. The second rupture occurred near Locust Grove, a rural area in Orange County, Virginia. About 92,000 gallons of fuel oil was released into the Rapidan River and then into the Rappahanock River, a source of drinking water for the City of Fredericksburg.

13) Federated Pipe Lines, Ltd. (Canada) Release on August 01, 2000

On August 01, 2000 about 450,000 gallons of crude oil was spilled into the Pine River in Northeastern British Columbia, Canada. The spill created an oil slick that was about 13 miles long and disrupted the region's water supply. Containment of the oil was aggravated because the pipeline ruptured in a section where the Pine River was very turbulent.

14) Petrobras (Brazil) Release on July 16, 2000

On July 16, 2000, about 1.1 million barrels of crude oil was spilled due to a pipeline burst at a petroleum refinery. Clean up activities were hampered by persistent rains. Although about 150,000 gallons were contained within the refinery grounds, about one million gallons of crude oil escaped into the Barigue River and eventually into the Iguacu River. Drinking water, farm land, and animal habitats along a 140-mile stretch of the rivers was disrupted.

15) Petrobras (Brazil) Release on January 18, 2000

On January 18, 2000, a pipeline ruptured in Petrobras's refinery in Rio de Janeiro's Guanabara Bay and spilled about 340,000 gallons of crude oil into the bay for seven hours before it was stopped. The spill fouled 17 rivers and estuaries and 12 square miles of coastline, contaminated protected mangrove swamps and killed seabirds, fish and crustaceans.

Appendix B Statistical Models for Performing Flood Frequency Analyses

Appendix B Statistical Models for Performing Flood Frequency Analyses

Statistical Models:

TYPE	PROGRAM	BY	AVAILABLE FROM	COMMENTS
	HEC FFA 3.1 (February 1995)	U.S. Army Corps of Engineers	Water Resources Support Center[3] Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Performs flood frequency analyses following *Bulletin 17B, Guidelines for Determining Flood Flow Frequency*, prepared by the Interagency Advisory Committee on Water Data (1982). Supersedes HECWRC.
	PEAKFQ 2.4 and up (April 1998)	U.S. Geological Survey	U.S. Geological Survey Hydrologic Analysis Software Support Team 437 National Center Reston, VA 20192 http://water.usgs.gov/software/surface_water.html	Performs flood frequency analyses following *Bulletin 17B, Guidelines for Determining Flood Flow Frequency*, prepared by the Interagency Advisory Committee on Water Data (1982).
	FAN	FEMA	Michael Baker, Jr., Inc. 3601 Eisenhower Avenue, Suite 600 Alexandria, VA 22304	Determines depth and velocity zones over alluvial fans.

[3]Program is typically distributed by vendors and may not be available through HEC. A list of vendors may be obtained through HEC.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix C Hydrologic Models for the Determination of Flood Hydrographs

Appendix C Hydrologic Models for the Determination of Flood Hydrographs

Hydrologic Models: Determination of Flood Hydrographs

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
Single Event	HEC-1 4.0.1 and up[2] (May 1991)	U.S. Army Corps of Engineers	Water Resources Support Center[3] Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.
	HEC-HMS 1.1 and up (March 1998)	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687 http://www.hec.usace.army.mil/	The Hydrologic Modeling System provides a variety of options for simulating precipitation-runoff processes. It has a capability to use gridded rainfall data to simulate runoff. It does not provide snowmelt and snowfall functions; it cannot be used for areas where snowmelt is an important flood hazard source and must be considered in estimation of flood discharges.
	TR-20 (February 1992)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.
	TR-55 (June 1986)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161 http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.html	Peak discharges and flood hydrographs at a single location.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix C Hydrologic Models for the Determination of Flood Hydrographs (cont'd)

Hydrologic Models: Determination of Flood Hydrographs

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	SWMM (RUNOFF) 4.30 (May 1994), and 4.31 (January 1997)	U.S. Environmental Protection Agency and Oregon State University	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720 http://www.epa.gov/ceampubl/swater/ Department of Civil, Construction, and Environmental Engineering Oregon State University 202 Apperson Hall Corvallis, OR 97331-2302 http://www.ccee.orst.edu/swmm/ ftp://ftp.engr.orst.edu/pub/swmm/pc/	Calibration or verification to the actual flood events highly recommended.
	MIKE 11 UHM (June 1999)	DHI Water and Environment	DHI Inc. 301 South State Street Newton, PA 18940	Simulates flood hydrographs at different locations along streams using unit hydrograph techniques. Three methods are available for calculating infiltration losses and three methods for converting rainfall excess to runoff. The web page is at: http://www.dhi.dk
	DBRM 3.0 (1993)	Bernard L. Golding, P.E. Consulting Water Resources Engineer Orlando, FL	Center for Microcomputers in Transportation (McTrans) University of Florida 512 Weil Hall Gainesville, FL 32611-6585	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.
	HYMO	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix C Hydrologic Models for the Determination of Flood Hydrographs (cont'd)

Hydrologic Models: Determination of Flood Hydrographs

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	PondPack v.8 (May 2002)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499 http://www.haestad.com	The program is for analyzing watershed networks and aiding in sizing detention or retention ponds. Only the NRCS Unit Hydrograph method and NRCS Tc calculation formulas are acceptable. Other hydrograph generation methods or Tc formulas approved by State agencies in charge of flood control or floodplain management are acceptable for use within the subject State.
Continuous Event	DR3M (October 1993)	U.S. Geological Survey	U.S. Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092	Calibration to actual flood events required. The web page is at: http://water.usgs.gov/software/surface_water.html
	HSPF 10.10 and up (December 1993)	U.S. Environmental Protection Agency, U.S. Geological Survey	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720	Calibration to actual flood events required. The web page is at: http://water.usgs.gov/software/surface_water.html
	MIKE 11 RR (June 1999)	DHI Water and Environment	DHI Inc. 301 South State Street Newton, PA 18940	The Rainfall-Runoff Module (RR, formerly NAM) is a lumped-parameter hydrologic model capable of continuously accounting for water storage in surface and sub-surface zones. Flood hydrographs are estimated at different locations along streams. Calibration to actual flood events is required. The web page is at: http://www.dhi.dk
Interior Drainage Analysis	HEC-IFH 1.03 and up	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Provides both continuous simulation and hypothetical event analyses. Coincidence frequency analysis (not included in the model) may be needed for some cases. Supporting documentation is available at: www.fema.gov/mit/tsd/dl_ifh.htm

[2]The enhancement of these programs in editing and graphical presentation can be obtained from several private companies.

[3]Program is typically distributed by vendors and may not be available through HEC. A list of vendors may be obtained through HEC.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix D Hydraulic Models for the Determination of Water Surface Elevations

Appendix D Hydraulic Models for the Determination of Water Surface Elevations

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
One-dimensional Steady Flow Models	HEC-RAS 2.2 (September 1998)	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687 http://www.hec.usace.army.mil/	A HEC-2 file can be imported into HEC-RAS; the user must change the conveyance computations in HEC-RAS and make the necessary modifications to the bridge modeling before running HEC-RAS to duplicate the results obtained using HEC-2. The WSPRO bridge analysis is recommended for constricted floodplains under subcritical flow conditions.
	HEC-RAS 3.0	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Under rare circumstances, for bridges with low flow, and weir flow on the overbanks, HEC-RAS 3.0 may not be able to balance the flow using weir flow equation and low flow bridge analysis methods. HEC-RAS 3.0 will then use the energy method, and the computed energy grade elevations and water-surface elevations may be on the high side.
	HEC-2 4.6.2[2] (May 1991)	US Army Corps of Engineers	Water Resources Support Center[3] Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Includes culvert analysis and floodway options.
	WSPRO (June 1988 and up)	US Geological Survey, Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA) web page at: http://www.fhwa.dot.gov/bridge/hyddescr.htm	Floodway option is available in June 1998 version. 1988 version is available on the USGS web page at: http://water.usgs.gov/software/surface_water.html
	FLDWY (May 1989)	US Department of Agriculture, Natural Resources Conservation Service	US Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161	Determines the encroachment stations from equal conveyance reduction method; used in conjunction with WSP2. Encroachment stations developed using this model must be re-entered in WSP2 model to properly develop floodway.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	QUICK-2 1.0 and up (January 1995)	FEMA	Federal Emergency Management Agency Hazard Identification Branch Mitigation Directorate 500 C Street, SW Washington, DC 20472	Intended for use in areas studied by approximate methods (Zone A) only. May be used to develop water-surface elevations at one cross section or a series of cross sections. May not be used to develop a floodway.
	HY8 4.1 and up (November 1992)	US Department of Transportation, Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA) web page at: http://www.fhwa.dot.gov/bridge/hyddescr.htm	Computes water-surface elevations for flow through multiple parallel culverts and over the road embankment. Software and related publication are available from Center for Microcomputers in Transportation (McTrans), University of Florida, 512 Weil Hall, Gainesville, FL 32611-6585; and on the web at: http://www-mctrans.ce.ufl.edu/
	WSPGW 12.96 (October 2000)	Los Angeles Flood Control District and Joseph E. Bonadiman & Associates, Inc.	Joseph E. Bonadiman & Associates, Inc. 588 West 6th Street San Bernardino, CA 92410 http://www.bonadiman.com	Windows version of WSPG. Computes water-surface profiles and pressure gradients for open channels and closed conduits. Can analyze multiple parallel pipes. Road overtopping cannot be computed. Open channels are analyzed using the standard step method but roughness coefficient can not vary across the channel. Overbank analyses cannot be done. Multiple parallel pipe analysis assumes equal distribution between pipes so pipes must be of similar material, geometry, slope, and inlet configuration. Floodway function is not available. Demo version available from: http://www.civildesign.com
	StormCAD v.4 (June 2002)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499 http://www.haestad.com	Perform backwater calculations. Should not be used for systems with more than two steep pipes (e.g. supercritical conditions). Inflow is computed by using the Rational Method; the program is only applicable to watershed which has the drainage area to each inlet less than 300 acres.
	PondPack v.8 (May 2002)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499 http://www.haestad.com	Cannot model ineffective flow areas. HEC-RAS or an equivalent program must be used to model tail water conditions when ineffective flow areas must be considered.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix D Hydraulic Models for the Determination of Water Surface Elevations (cont'd)

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	Culvert Master v.2.0 (September 2000)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499 http://www.haestad.com	Compute headwater elevations for circular concrete and RCB culverts for various flow conditions.
One-dimensional Unsteady Flow Models	HEC-RAS 3.0	US Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687 http://www.hec.usace.army.mil	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation unavailable.
	FEQ 8.92 and FEQUTL 4.68 (1997, both)	Delbert D. Franz, Linsley, Kraeger Associates; and Charles S. Melching, USGS	US Geological Survey 221 North Broadway Avenue Urbana, IL 61801 http://water.usgs.gov/software/surface_water.html and technical support available at http://www-il.usgs.gov/proj/feq/	The FEQ model is a computer program for the solution of full, dynamic equations of motion for one-dimensional unsteady flow in open channels and control structures. The hydraulic characteristics for the floodplain (including the channel, overbanks, and all control structures affecting the movement of flow) are computed by its companion program FEQUTL and used by the FEQ program. Calibration or verification to the actual flood events highly recommended. Type 5 culvert flow computations of FEQUTL need verification with results obtained using methodology or models accepted for NFIP use. Floodway concept formulation is unavailable.
	ICPR 2.20 (October 2000) and 3.02 (November 2002)	Streamline Technologies, Inc.	Streamline Technologies, Inc. 6961 University Boulevard Winter Park, FL 32792 http://www.streamnologies.com	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation unavailable; however, version 3 allows user to specify encroachment stations to cut off the cross section.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix D Hydraulic Models for the Determination of Water Surface Elevations (cont'd)

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	SWMM 4.30 (May 1994), and 4.31 (January 1997)	US Environmental Protection Agency and Oregon State University	Center for Exposure Assessment Modeling US Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720 http://www.epa.gov/ceampubl/swater/ Department of Civil, Construction, and Environmental Engineering Oregon State University 202 Apperson Hall Corvallis, OR 97331-2302 http://www.ccee.orst.edu/swmm/ ftp://ftp.engr.orst.edu/pub/swmm/pc/	Calibration or verification to the actual flood events highly recommended. Structural loss calculations unavailable and must be accommodated via roughness factor manipulation. Floodway concept formulation unavailable. Preferably, for NFIP purposes, head losses at bridges should be verified using WSPRO; losses at culverts should be verified using the US Geological Survey's six equations for culvert analysis. Losses at storm sewer junctions should also be verified with separate calculations; contact FEMA for guidance with these calculations. Supporting documentation for floodway calculations is available at: http://www.fema.gov/mit/tsd/dl_swmm.htm.
	UNET 4.0 (April 2001)	US Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Calibration or verification to the actual flood events highly recommended. Comparison of bridge and culvert modeling to other numerical models reveals significant differences in results; these differences may be investigated in the near future. Floodway option currently under review, not accepted for NFIP usage.
	FLDWAV (November 1998)	National Weather Service	Hydrologic Research Laboratory Office of Hydrology National Weather Service, NOAA 1345 East-West Highway Silver Spring, MD 20910	Includes all the features of DAMBRK and DWOPER plus additional capabilities. It is a computer program for the solution of the fully dynamic equations of motion for one-dimensional flow in open channels and control structures. Floodway concept formulation is unavailable. Calibration to actual flood events required. This model has the capability to model sediment transport. Program is supported by NWS. Supporting documentation is available at: http://www.fema.gov/mit/tsd/dl_fdwv.htm

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix D Hydraulic Models for the Determination of Water Surface Elevations (cont'd)

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	MIKE 11 HD (June 1999)	DHI Water and Environment	DHI Inc. 301 South State Street Newton, PA 18940	Hydrodynamic model for the solution of the fully dynamic equations of motion for one-dimensional flow in open channels and control structures. The floodplain can be modeled separately from the main channel. Bridge flow computations need verification with results obtained using methodologies or models accepted for NFIP usage. Calibration to actual flood events required. Floodway concept formulation is unavailable. This model has the capability to model sediment transport. The web page is at: http://www.dhi.dk
	FLO-2D v. 2000.11 (December 2000)	Jimmy S. O'Brien, Ph.D., P.E.	FLO-2D Software, Inc. Tetra Tech, ISG P.O. Box 66 Nutrioso, AZ 85932	Hydrodynamic model for the solution of the fully dynamic equations of motion for one-dimensional flow in open channels and two-dimensional flow in the floodplain. Bridge or culvert computations must be accomplished external to FLO-2D using methodologies or models accepted for NFIP usage. Calibration to actual flood events required. Floodway computation is unavailable.
Two-dimensional Steady/Unsteady Flow Models	TABS RMA2 v. 4.3 (October 1996) RMA4 v. 4.5 (July 2000)	US Army Corps of Engineers	Coastal Engineering Research Center Department of the Army Waterways Experiment Station Corps of Engineers 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Limitations on split flows. Floodway concept formulation unavailable. More review anticipated for treatment of structures.
	FESWMS 2DH 1.1 and up (June 1995)	US Geological Survey	US Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092 http://water.usgs.gov/software/surface_water.html	Region 10 has conducted study in Oregon. Floodway concept formulation unavailable. This model has the capability to model sediment transport.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Appendix D Hydraulic Models for the Determination of Water Surface Elevations (cont'd)

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
	FLO-2D v. 2000.11 (December 2000)	Jimmy S. O'Brien, Ph.D., P.E.	FLO-2D Software, Inc. Tetra Tech, ISG P.O. Box 66 Nutrioso, AZ 85932	Hydrodynamic model that has the capabilities of modeling unconfined flows, complex channels, sediment transport, and mud and debris flows. It can be used for alluvial fan modeling.
Floodway Analysis	SFD	US Army Corps of Engineers/FEMA	Federal Emergency Management Agency Hazard Identification Branch Mitigation Directorate 500 C Street, SW Washington, DC 20472	Simplified floodway procedure for streams with no regulatory floodway limits.
	PSUPRO	Pennsylvania State University/ US Army Corps of Engineers/FEMA	Federal Emergency Management Agency Hazard Identification Branch Mitigation Directorate 500 C Street, SW Washington, DC 20472	Encroachment analysis for streams with no regulatory floodway limits.

[2]The enhancement of these programs in editing and graphical presentation can be obtained from several private companies.

[3] Program is typically distributed by vendors and may not be available through HEC. A list of vendors may be obtained through HEC.

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Note: Model information from FEMA web site: http://www.fema.gov/mit/tsd/en_modl.htm

Surface Hydrology Analysis

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