Comprehensive Modeling: Inventorying Directly and Indirectly Affected High Consequence Areas

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Abstract

Regulations for pipeline operators within the Oil and Gas Pipeline Industry are becoming increasingly rigorous, especially in the fields of pipeline integrity and emergency response. This paper focuses on the rules and guidelines set forth in the Department of Transportation 49 CFR 195.452 "Pipeline Integrity Management in High Consequence Areas" and covers the specific requirements of this ruling to perform a High Consequence Area analysis using a Geographic Information System (GIS). A spatial analysis process is described in this paper as a means of best meeting the regulatory guidelines.

Introduction

The aim of High Consequence Area (HCA) analysis is to identify all segments of a pipeline system having the potential to affect an HCA either directly or indirectly. As such, any comprehensive HCA analysis process must involve procedures to account for directly and indirectly affected HCAs.

Determining directly affected HCAs is a relatively basic analysis and one that the pipeline industry has conquered. On the other hand, effectively determining indirectly affected HCAs remains a challenge to the pipeline industry due to the complexity surrounding fluid transport resulting from a leak or spill.

High Consequence Areas

High Consequence Areas are really just that, areas of concern that may or may not be in close proximity to a pipeline that if affected by a pipeline release could result in drastic consequences. In general, HCAs are split into groupings of population density, environment, cultural, and economic. Population density is broken into high and other population areas; environment is comprised of drinking water sources, ecological sensitive areas, and national fish hatcheries; cultural is still under development but includes such things as national parks, cultural resources, recreational resources, and tribal resources; and commercial which covers commercially navigable waterways and other economic resources.

Directly Affected HCAs

Directly affected HCAs are those HCAs located along a pipeline alignment. For example, an urban center through which a pipeline travels. HCAs that are directly affected by a pipeline are relatively simple to identify within a GIS environment since the core functionality required to perform this type of analysis is integral to any GIS.

The process to determine directly affected HCAs is less dependent on GIS functionality and more dependent on data completeness. That is, it is not possible to identify HCAs that do not exist in the input datasets.

Data Sources

There are two main sets of information needed in order to carry out an analysis capable of identifying directly affected HCAs. One set of information is the location of the pipeline alignment and the other is a composite of all High Consequence Areas along the pipeline alignment.

The pipeline alignment is typically derived from survey information but may be available through some type of data conversion or acquisition process. For instance, inline inspection techniques with inertial equipment, field based survey, or estimated pipeline centerlines from legal plans.

The Office of Pipeline Safety (OPS) manages an initiative called the National Pipeline Mapping System which has a mandate to collect and distribute pertinent information for pipeline operators. For the most part, all HCA data endorsed by the OPS for use in an HCA analysis is available from the National Pipeline Mapping System.

Analysis Process

The process undertaken to determine directly affected HCAs has only a few steps and is relatively straightforward and depicted in **Figure 1**.

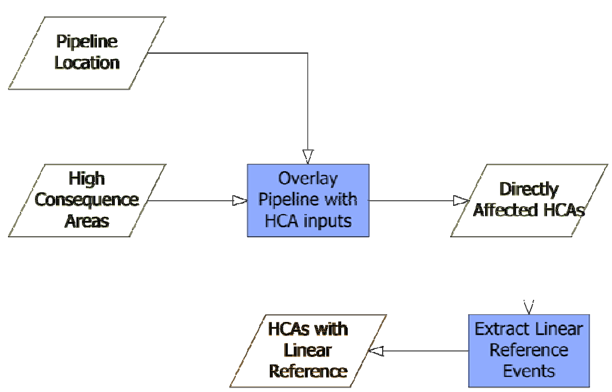

Figure 1 – Process for Determining Directly Affected HCAs

The basic inputs and steps to produce an inventory of directly affected HCAs are as follows:

1. Prepare and Input Pipeline Location and High Consequence Area data sets
2. Select High Consequence Areas that intersect the Pipeline Location
3. Produce tabular listing of Directly Affected HCAs
4. Calculate intersection points between Pipeline Location and High Consequence Areas

5. Translate intersection points into linear referenced coordinates

Indirectly Affected HCAs

Determining indirectly affected HCAs requires a much more rigorous set of analysis tools. The reason for the increased level of complexity is related to inherent complexity of modeling the distance traveled by thermal radiation, in the event of a jet fire release, or an uncontrolled liquid leak or spill.

Reasonable models exist to determine thermal radiation distances based on fluid release rate and fluid properties. However, for fluids having a low likelihood of ignition upon release (i.e. low vapor pressure hydrocarbons and crude oil) the distance by which the release may affect an HCA is governed by channel (stream, river, culvert, etc) and overland flow. Channel flow covers the instance where a leak or spill falls in very close proximity to a river, creek, stream, culvert, ditch line, or other confined channel. Modeling of channel flow is well understood and implemented within a GIS with only a moderate degree of effort. Unfortunately, the majority of cases for fluid transport are not governed preliminarily by channel flow but by rather by overland flow, a model much more difficult to implement within a GIS due to its intricacies and data requirements.

Data Sources

There are three main sets of information needed in order to carry out an analysis capable of identifying indirectly affected HCAs. One set of information is the location of the pipeline alignment, another is a composite of all High Consequence Areas along the pipeline alignment, and the last is a series of data inputs used to delineate the overland flow.

Guidance on data inputs for the overland flow is provided in 49 CFR 195.452 and is summarized in **Figure 2** below along with some additional recommended flow parameters [1]. Reading the pyramid in **Figure 2** from bottom to top shows how each data input builds upon the next. Layers of the pyramid near the bottom are the foundation of the model but nearer to the top the data inputs may be removed from the model and replaced with constant values or assumptions without causing too much deviation from a realistic model.

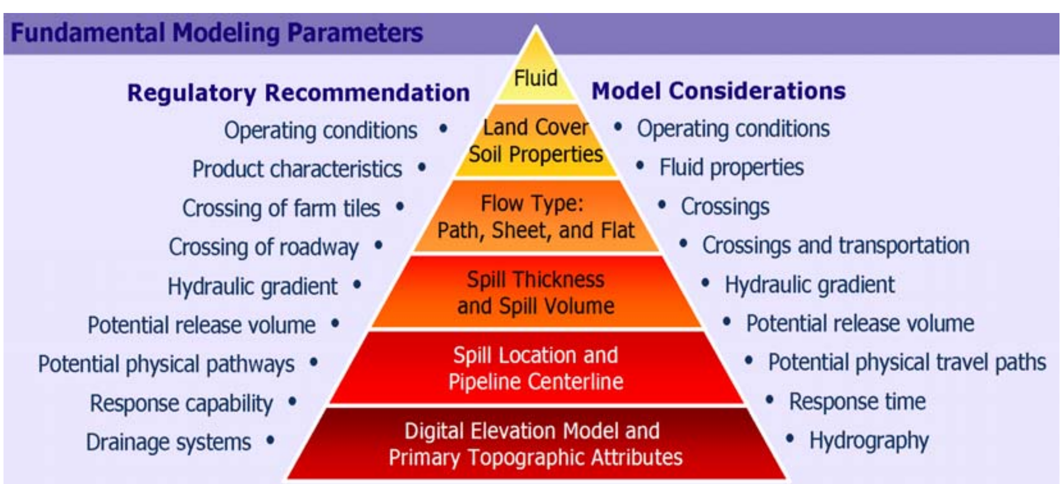

Figure 2 – Fundamental Overland Flow Data Inputs and Constraints

Analysis Process

The process for determining indirectly affected HCAs begins with an overland flow modeling component. This model requires many inputs (**Figure 2**) but the main input is a flow resistance surface for fluid movement over the ground. The flow resistance is based upon a digital elevation model, directional slope, flow coefficients, and fluid properties.

With a realistic flow resistance surface established the next step is to calculate the path or paths that a fluid could make as it moves over a digital elevation model. The paths the model produces can be constrained based on a time limit or potential spill volume.

With the potential flow distance calculated it is then possible to determine which of the HCAs could be affected by the fluid release. This is accomplished through traditional intersection or overlay procedure within a GIS.

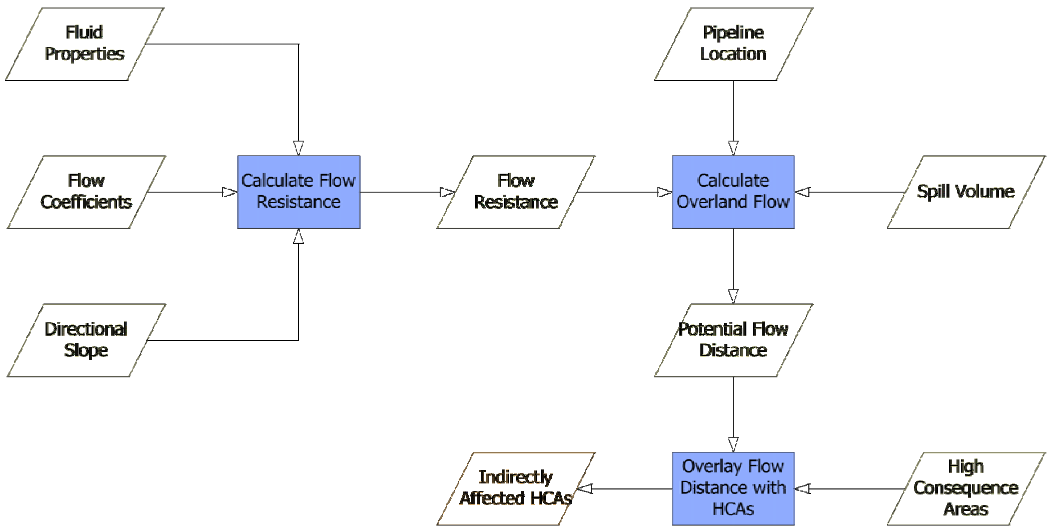

Figure 3 – Process for Determining Indirectly Affected HCAs

In more detail the complete process (**Figure 3**) for determining indirectly affected HCAs are as follows:

1. Gather and prepare digital elevation model, directional slope, flow coefficients, and fluid properties for input into the flow resistance calculation
2. Calculate flow resistance
3. Input Pipeline Location and Spill Volume (or a time limit) into the overland flow model
4. Determine potential flow distance
5. Overlay flow distance extents with HCAs
6. Produce inventory of indirectly affected High Consequence Areas

Management of Analysis Results

One of the key benefits of performing HCA analysis within a geographic information system is the capability of integrating the analysis and analysis output with a relational database. Storage of analysis results in a structured relational database provides the ability for performing audit queries and running reports. In this instance, a database following the Pipeline Open Data Standard (PODS) was modified with an enhanced HCA table to allow for storage of complete HCA analysis results.

After the analysis results are automatically populated into the HCA database table, they are then immediately available for re-use within the geographic information system. In addition, once populated in the database, triggers can be fired to automatically prompt the appropriate personnel to undertake remediation activity for the identified HCAs. These functions were made available through a database front-end application along with additional functionality for managing the results, site visitations, and analysis results validation.

Summary

Regulations for pipeline operators within the Oil and Gas Pipeline Industry are becoming increasingly rigorous, especially in the fields of pipeline integrity and emergency response. Spatial analysis processes used to meet the requirements of regulators must be comprehensive, repeatable, and defensible.

References

[1] Denby, Allison; Humber, J, “Overland Flow: Comparison of Modeling Methods”, September 2004, 13th Annual GIS for Oil & Gas Conference & Exhibition

Biography: Lori Odegard

Lori began her career in the Oil and Gas industry with the Alberta Energy Utility Board (EUB) as a Geological Technician and spent eight years with the EUB. In 1990, she moved into the pipeline operations group of BP Canada's Natural Gas Liquids Business Unit (NGLBU). With over 14 years of experience in all aspects of pipeline operations, Lori chose to move into a key technical role within the NGLBU to support and provide direction for the Business Units ongoing Geographic Information System implementation efforts. Lori continues to hold the Senior GIS Analyst role in BP Canada and her commitment to GIS Analysis and System Integration continues to prove the business benefits realized from applying GIS to pipeline operations. More recently, Lori joined the board of the GITA Alberta Chapter and holds positions on several of its committees.

Publications and Presentations
"Pipeline Integrity Management", BP Integrity Forum Houston 2004
"Digital Emergency Preparedness: Planning for the Unexpected", Co-presented at GeoAlberta 2004
"Facilitating Precision, Speed and Security with a Global Navigation Tool", GITA Alberta Chapter Educational Event on System Integration, September 2004
"Integrity Management: Automated Analysis for Class Location", Co-author and Co-presenter, International Pipeline Conference 2004

Biography: Jason Humber

Jason Humber founded Integrated Informatics Inc. in October of 2002 to provide data management and system design consulting services to the pipeline industry for new construction, operations, and pipeline integrity. As a Principal Consultant, Jason is responsible for corporate level development and delivery of Integrated Informatics unique suite of services. In 1999, Jason began his career with the Natural Gas Business Unit of BP Canada Energy Company in Calgary, Alberta. His primary focus within BP was development of a business unit wide data management system that supported the analytic and integration needs of pipeline integrity. While working with BP, Jason also took on a pivotal role on the project management team within the Alaska Gas Producers Pipeline Team and helped to establish the processes required for Project Data Management. More recently, Jason has completed a similar advisory role with the Mackenzie Gas Project, and has broadened and implemented these data management approaches to encompass the needs of developing oil sands projects.