Appendix 1. Key Variables in Oil Spill Impact Framework

Table A1.1 Oil spill variables

Variable	Effect	Citations
Ship safety features	Double-hulled ships are less accident-prone than single-hulled ships and spills from double-hulled ships may be less costly.	Burgherr 2007; Nyman 2009; Alló and Loureiro 2013
Location of spill	Offshore spills have less direct economic impacts than nearshore spills in proximity of human populations.	White and Molloy 2003; Kontavos et al. 2010
Spill amount and rate	Increased amount of oil spilled increases total damages. Continued release of oil over months necessitates multiple waves of response efforts.	White and Molloy 2003; Loureiro et al. 2005; Punzon et al. 2009; Alló and Loureiro 2013
Type of oil	Chemical composition of oil influences dispersal characteristics (distance, depth, and degradation rate) and toxicity.	McCoy and Whittier 2003; Herrington et al. 2006

Table A1.2 Disaster management variables

Variable	Effect	Citations
Timing of response	A rapid response can reduce oil spill impacts by orders of magnitude.	U.S. Department of Commerce 1983; Grigalunas et al. 1986; White and Baker 1998; White and Molloy 2003; Nyman 2009
Governance	Response plans and on-scene command structures play a critical role in reducing impacts.	U.S. Department of Commerce 1983; Rodin et al. 1992; Ritchie 1995; White and Molloy 2003
Response technology	The mix of technologies used to respond (e.g., dispersants, skimmers, manual collection) can increase or decrease response efficiency. These technologies may also create their own short- and long-term damages. Improvements in technology are also driving up response costs.	George 1961; Foster et al. 1990; De Vogelaere and Foster 1994; Ritchie 1995; Moore et al. 1998; Pearson et al. 1998; Trudel 1998; White and Baker 1998; Cohen et al. 2001; White and Molloy 2003; Vosyliene et al. 2005; Franklin and Warner 2011; Cheong 2012; Fingas 2012
Human capital	The use of volunteers, military, and other non-market labor can affect response costs (both positively and negatively).	Loureiro et al. 2005; Cheong 2011; Fourcade 2011; Tucker and O'brien 2011
Natural processes	Oil-eating bacteria and other natural processes affect recovery times. Some natural process can be reduced by human cleanup strategies (e.g., dispersants can affect oil-eating bacteria).	Hazen et al. 2010; Gutierrez 2011; Hamdan and Fulmer 2011.
Local culture and context	The scale of cleanup demanded by citizens is culturally specific (i.e., different countries require different levels of recovery) and has increased over time. Also, costs vary by local economic context. Response and recovery are more expensive in some countries than others.	Wirtz et al., 2007; Nyman, 2009; Kontovas et al., 2010; Alló and Loureiro, 2013; Fingas, 2013

Table A1.3 Marine physical environment variables

Variable	Effect	Citations
Connecting waterways	Interconnectivity of waterways allows oil to leave the waterway where the spill occurred and enter other waterways, impacting other municipalities	
Tides and currents	Ambient tide and current conditions will dictate the dispersal rate and direction of the spilled oil	e.g., Hodgins et al. 1991; Sheng and Hodgins 2004; David Suzuki Foundation 2013
Wave exposure	Sites exposed to waves will exhibit increased rates of natural degradation of oil over sheltered waterways	Owens et al. 1987; Carls et al. 2001
Temperature and salinity	Temperature and salinity influence solubility of oil, rates of oil degradation and effectiveness of oil dispersants	Whitehouse 1984; Blondina et al. 1999; Chandrasekar et al. 2006
Substrate at site exposed to oil	Contrary to sites with rocky substrate, oil can penetrate deeply into sandy sediments and can persist for decades	Carls et al. 2001; Li and Boufadel 2010
Weather conditions	Prevalent winds may change the dispersal patterns of surface oil (favourably or unfavourably) and may inhibit response efforts	Moldan et al. 1985; Law and Kelly 2004; Wirtz et al. 2007

Table A1.4 Marine biology variables

Variable	Effect	Citations
Exposure to toxins	Heavy crude oil products are often diluted with toxic chemicals, posing an additional hazard	e.g., Stubblefield et al. 1989; Upreti et al. 2007
Exposure quantity	Increased oil exposure increases initial injury as well as recovery time (usually non-linearly)	Silliman et al. 2012
Habitat/ depth of species	Subsurface species will have reduced exposure to oil (assuming that the majority of the oil does not sink), while species near the surface and in intertidal zones will have the highest exposure to oil	
Mobility	Highly mobile species may be able to move away from spill areas, reducing their exposure, while sedentary species are not	
Feeding mode	Filter-feeding species tend to accumulate oil while feeding and are particularly vulnerable	Law and Hellou 1999
Species identity	Even closely related species at the same site can differ in their susceptibility to and recovery from an oiling event	e.g., North 1973
Other stressors	Toxic effects of oil can be additive or synergistic with other environmental stressors	Peterson et al. 2003; Sargian et al. 2007; Holmstrup et al. 2010; Sundbäck et al. 2010
Developmental stage	Larvae and early developmental stages are particularly vulnerable to oil toxicity	Wells 1972; Chia 1973; Rice et al. 2001; Kazlauskiene et al. 2008
Generation time	Generally, species with slower generation times take longer to recover from a spill event	Conan et al. 1982

Table A1.5 Human health and society variables

Variable	Effect	Citations
Direct skin contact with carcinogenic compounds	The composition of crude oil contains Volatile Organic Compounds (VOCs), which are carcinogenic and may affect the nervous system. They may also have a range of lesser effects and irritations.	Jenssen 1996; Ormseth and Ben-David 2000; Baars 2002; Herrington et al. 2006; Rodríguez-Trigo et al. 2007; Ha et al. 2008; Major and Wang 2012.
Air pollutants	Air pollutants from oil spills can affect human health and exacerbate pre-existing conditions.	Davidson et al. 2005; Jacques Whitford AXYS Ltd. 2008
Ingestion of contaminated food and water	Adverse health impacts via ingestion are also possible by eating potentially contaminated seafood, drinking contaminated water, or other forms of ingestion	Szaro 1977; Piatt et al. 1990; Hofer 1998; Law and Hellou 1999; Ormseth and Ben-David 2000; Webster et al. 2006; Matkin et al. 2008; Aguilera et al. 2010; Gohlke et al. 2011; Barron 2012
Psychological and social costs	Work stoppages, shorter life expectancy, and other effects impact the economy. Moreover, increases in stress, drug and alcohol abuse, crime, etc., create further social costs.	Rodin et al. 1992; Palinkas et al. 1993; Moore et al. 1998; Picou et al. 2004; Loureiro et al. 2005
Subsistence uses	Impacts on subsistence economies, social and cultural uses of natural resources, and social structures are routine. This may also impact other ethnic and social enclaves.	Rodin et al. 1992; Palinkas et al. 1993; Martin 1999; Fall et al. 2001; Esclamado 2011; Rhoan 2011

Table A1.6 Economic variables

Variable	Effect	Citations
Commercial fisheries and aquaculture	Fisheries businesses suffer direct losses from product mortality, harvesting closures, loss of market demand, brand damage, etc.	Moldan et al. 1985; Grigalunas et al. 1986; Moncrieff and Simpson 1993; Goodlad 1996; Pearson et al. 1998; Martin 1999; Moller et al. 1999; Law and Kelly 2004; Loureiro et al. 2005; Garza-Gil et al. 2006; Surís-Regueiro et al. 2007; Punzon et al. 2009; Cheong 2012
Commercial fisheries and aquaculture value chain	Due to direct losses, businesses that depend on commercial fisheries such as docks, processors, distributors, and supply companies lose product inputs and markets.	U.S. Department of Commerce 1983; Moncrieff and Simpson 1993; Garcia Negro et al. 2009
Tourism industry	Brand damage from an oil spill can impact businesses providing accomodations, transportation, guides, activites (e.g. recreational fishing), tourism-related retail, etc. These market impacts can spread beyond the direct oil spill zone.	U.S. Department of Commerce 1983; McDowell Group 1990; Butler and Fennell 1994; Hill and Bryan 1997; Moore et al. 1998; Martin 1999; McCammon 2003; Loureiro et al. 2005; Garza et al. 2009; Oxford Economics 2010; Danielson 2011
Waterway usage	An oil spill may impede or shut down waterway uses, so the greater the use of a waterway, the larger the effect of its closure	
Other marine-based industries	Industries that pump water for cooling and other processes are vulnerable to oil spills. Transportation industries such as ferries and float planes may also be affected.	U.S. Department of Commerce 1983; Moore et al. 1998
Oil industry	The oil industry itself may lose access to products or markets through affected waterways, and may be subject to regulatory moratoria on operations.	Moncrieff and Simpson 1993; Moore et al. 1998; Greater New Orleans Inc. 2011
Agriculture	Marine-based agriculture (e.g., seaweed farms) can be affected, and farms adjacent to waterways may be affected by airborne mists or damage from cleanup operations.	U.S. Department of Commerce 1983; Moller et al. 1999
Pure economic loss	Losses that occur independently of direct damage. These damages may ripple across the economy, spreading to goods and services providers that rely on spending from affected populations.	Grigalunas et al. 1986; Palmer 2011; Perry 2011

Passive use and recreation	Non-market losses to natural environments and recreational opportunities are usually significant results of an oil spill.	Assaf et al. 1986; Carson et al. 2003; McCammon 2003; Peterson et al. 2003; Garza et al. 2009; Loureiro et al. 2009; Fourcade 2011
Real estate	"Pure stigma" losses that devalue coastal or regional properties due to adjacency to the spill.	Grigalunas et al. 1986; Oxford Economics 2010; Smith et al. 2010; Cheong 2012; Pickrell 2012
Financial sector	Lending and credit markets can be affected by defaults from impacted businesses. Shareholders may lose value from falling share prices. The economy may experience inflation.	U.S. Department of Commerce 1983; Moncrieff and Simpson 1993; Palinkas et al. 1993; Smith et al. 2010
Legal and research costs	Oil spills require interventions by the legal profession to negotiate claims, and extensive research to establish baselines and measure impacts.	U.S. Department of Commerce 1983; Law and Kelly 2004; Loureiro et al. 2005; Liu and Wirtz 2006; Fourcade 2011; Minder 2012
Municipal/regional government impacts	Direct administrative costs, increased demand for public services, and loss of tax revenues can strain government budgets. Opportunity costs, loss of staff to cleanup efforts, municipal/ regional brand damage, and political fallout are also factors impacting governments.	Rodin et al. 1992; Palinkas et al. 1993; Moncrieff and Simpson 1993; Hill and Bryan 1997; Moore et al. 1998; Picou et al. 2004; Cheong 2011
Economies of scale	Once initial costs are invested into a cleanup, marginal costs of additional oil decrease per gallon.	Etkin 2004; Brody et al. 2012
Recovery boom	Short-term economic losses are offset by increases in spending related to the response and recovery. Tourism businesses, retail, contractors, and local labor can all benefit.	U.S. Department of Commerce 1983; McDowell Group 1990; Butler and Fennell 1994; Clark et al. 1997; Hill and Bryan 1997; Moore et al. 1998; Loureiro et al. 2005; IEM 2010; Cheong 2011; Danielson 2011; Hall et al. 2011; Palinkas et al. 2011; Rodin et al. 2011
Expense savings	Business losses are offset by reduced spending on variable costs of production or services (e.g. commercial fishers spend less on diesel, bait, etc.).	U.S. Department of Commerce 1983; Loureiro et al. 2005; Garza-Gil et al. 2006
Tax revenues	Due to increased recovery spending, governments may experience short-term tax revenue increases on sales of goods and services.	U.S. Department of Commerce 1983; Barker 2011
Conservation benefits	By limiting access to commercial fisheries and certain geographies, there may be conservation benefits to targeted species.	Hill and Bryan 1997; Moller et al. 1999; Loureiro et al. 2005; Punzon et al. 2009

Table A1.7 Policy and decision variables

Variable	Effect	Citations
Port closure	Marine transport losses are usually only a fraction of oil spill losses, though some examples of port closures due to river-based spills have been noted.	Wirtz, et al. 2007; Nossiter 2008; Sayre 2012; Farm Futures 2013; Muskal 2013
Brand campaigns	In addition to losses, further investments may be required to revive local brands in the fisheries, tourism, and municipal sectors.	Grigalunas et al. 1986; Moncrieff and Simpson 1993; Goodlad 1996; Moore et al. 1998; Loureiro et al. 2005; Cheong 2012; Finn 2012
Compensation payments	Transfers from compensatory regimes and other sources can offset individual losses and soften the economic impact of oil spills.	Butler and Fennell 1994; Punzon et al. 2009; Barker 2011; Ritchie et al. 2011
Fishing moratoria	Fisheries bans cause direct losses to fisheries businesses, but such losses are admissible under compensation regimes.	IOPC 2007