# RESPONSE OPTIONS CALCULATOR (ROC)

## TECHNICAL DOCUMENTATION

Table of Content

## Introduction

Gauging the performance of oil spill response equipment has long been of interest for government regulators, oil spill responders, and the oil industry. The Oil Pollution Act of 1990 (OPA'90) and Executive Order 12777 resulted in regulations that contain minimum on-water oil removal equipment requirements for facility and vessel response plans. For example, for skimmers, the effective daily recovery capacity (EDRC) is a calculation that multiplies the manufacturer's rated throughput capacity over a 24-hour period by 20 percent. This 20 percent efficiency factor takes into account the limitations of the recovery operations due to available daylight, sea state, temperature, viscosity, and emulsification of the oil being recovered. A similar planning standard for dispersants is the Effective Daily Application Capacity (EDAC). EDAC calculations assume an application rate or dosage of five (5) gallons of dispersant over one (1) acre at a dispersant-to-oil ratio (DOR) of 1:20 and an oil slick length of four (4) nautical miles. It must be recognized that these are planning standards and not performance standards. While EDAC calculations can be closer to reality than EDRC, use of EDAC and especially EDRC at oil spill response exercises and at actual oil spill incidents as a measure of actual performance potential is inappropriate.

ASTM F1780 Guide for Estimating Oil Spill Recovery System Effectiveness, ASTM F631 Guide for Collecting Skimmer Performance Data in Controlled Environments, and ASTM F1607 Guide for Reporting of Test Performance Data for Oil Spill Response Pumps provide some guidance in estimating potential response system performance. F631 defines encounter rate, throughput efficiency, and recovery efficiency.

It is not possible to recover, disperse, or burn more oil than that which is encountered. The Response Options Calculator (ROC) uses encounter rate calculations with hourly modeled values for spilled oil average thicknesses to provide state-of-the-art estimates of potential response performance. This document is the technical documentation for the methods, assumptions, and calculations used in ROC.

## Acknowledgements

The original ROC development project was funded by Shell Oil, the American Petroleum Institute, the Marine Minerals Service of the US Department of the Interior, Genwest Systems and Spiltec. Funding for this technical documentation was provided by ExxonMobil.

## The Response Options Calculator (ROC)

The Response Options Calculator models assessment of oil spill response system performance involving mechanical recovery, dispersant application, and the burning of oil (*In-Situ*) after a spill, real or simulated. All three options make use of Encounter Rate. Encounter Rate (EnR) is a function of the average thickness of the oil slick (t), the speed of advance of the response system (v) and the swath (w) of the response system.

$$EnR\ [\text{gallons per minute}] = 63.13 \times t\ [\text{inches}] \times w\ [\text{feet}] \times v\ [\text{knots}] \quad (1)$$

Note: "Oil" can be a crude oil or a refined oil product. As oil weathers it may form a stable water-in-oil emulsion. As used in this document, an oil slick is defined to be oil and/or emulsion. If ROC weathering is used, hourly values of emulsification are calculated to obtain values of recovery, dispersion, and burning for just the "oil" portion of the slick.

An average thickness of the oil slick from weathering and spreading algorithms in the ROC weathering module is provided for every hour of the simulation. (Link to ROC weathering code –Code\models\weathering\OilWx.as)
ROC spreading algorithms are described by J.A. Galt and Roy Overstreet[1]. ROC is available as a free download at http://www.genwest.com.

The Response Options Calculator was built in Adobe Flex and, with the appropriate plug-in, operates with any Internet web browser. There were three unique requirements for this project:

- The application could not be an executable as it is difficult to obtain permission to install executables on many industry and government computers.
- The application had to be able to run as a stand-alone (no Internet).
- Users of the application needed to be able to save their files for later use.
-

Throughout this document are Hyperlinks to the appropriate section of source code.

This document contains the algorithms and calculations used for mechanical recovery, dispersant application, and burning of oil as used in the ROC. These algorithms were originally developed by Alan A. Allen[2] and have been used in the Mechanical Equipment Calculator ™ (MEC), the Dispersant Mission Planner™ (DMP), the Dispersant Mission Planner 2 (DMP2), and the In Situ Burn Calculator ™ (ISB). The MEC, DMP, and ISB are known collectively as Spill Tools™ and are available for download from the NOAA Office of Response and Restoration web site http://www.response.restoration.noaa.gov. The DMP2 is an update of the DMP and is also available from this NOAA web site. The DMP2 is cited as one method for EDAC calculations in the U.S. Coast Guard's Final Rule for vessel and facility response plans for oil[3].

Limitations and Assumptions Used in ROC

Calculations in ROC are based on the assumption that a spill takes place and remains offshore in open water without interference from ice or debris. ROC is not geographically specific; however, it uses the general location and time zone specified by the user to establish times of sunrise and sunset. While ROC's default is set for daylight operations only, you can override this constraint and let specific response systems operate at night.

ROC predicts that oil thickness will vary within a given slick, the average thickness being determined with a combination of calculations involving the oil characteristics and environmental conditions selected. You may also elect to ignore such effects and simply assign a constant oil thickness for the entire simulation period. ROC assumes that responders are always using best practices, so that response systems are working in the thickest part of the slick, and that the oil within that thick region is distributed uniformly.

An important feature of ROC is that calculations involving oil changes (if the weathering mode is selected) and system performance are performed over a "Calculation Interval" that is set for 1 hour. This allows for a more accurate assessment of oil changes and reductions (whether natural or from response); and, if you elect to ignore weathering of the oil, a long period of interest (say several days) could be simulated using constant oil thickness for short periods of only a few hours (or "calculation intervals") per "Simulation Period".

Assigned skimming systems are assumed to be collecting at a constant rate. Actual recovery of oil/emulsion by skimmers can be intermittent as necessary to accumulate sufficient thickness to maximize efficiency of recovery. At any point the Total Fluid Recovery Rate (TFRR) cannot exceed the nameplate recovery rate of the system. If this occurs, ROC will reduce the Throughput Efficiency so that the TFRR = Nameplate.

To simplify computations, ROC holds some factors constant that in reality would probably change. For example, during a real response, a skimming system's swath width might be altered over time as the nature and amount of oil on the surface change. However, the swath for a given response system remains constant in ROC for the duration of a simulation.

Wind direction or ocean currents are not considered in ROC since ROC does not consider changes in the location of a slick (relative to land) during a simulation period. The location of a slick (i.e., its proximity to shore) only comes into play as it might affect assigned "Transit Times" for response systems to travel between their staging, offloading, or burn sites and the area in which they are operating.

Oil is removed from the ocean surface by natural processes (e.g., evaporation) when the oil weathering mode is used, and by one or more response systems throughout a given simulation period. Oil remaining on the surface during a calculation interval is always available to the selected response systems because oil is never allowed to "come ashore". Recall that ROC is not geo-specific.

Wind speed, however, is considered in ROC as it affects oil slick thickness, weathering phenomena, and system performance. Wind speed is not considered as a factor that would influence a slick's spatial orientation or its proximity to shore. If an average oil thickness is not specified for a given simulation period, ROC will use wind speed and other factors to estimate changing oil properties and average oil thickness.

When the weathering mode is selected, ROC also estimates such things as the changing water content (emulsification) of the oil being simulated, and the viscosity of the oil. The viscosity is used within each calculation interval (along with the designated wind speed) to assess how each of the response options (recovery, burning and dispersants) might be affected. Efficiency plots have been provided for a broad range of skimming systems and for nominal conditions involving burning and dispersant application as well. If you do not provide specific values for Recovery Efficiency, Burn Efficiency, and Dispersant Efficiency as fixed input values for a given simulation, ROC will use efficiency values based on these plots. You may elect to have ROC use "low", "nominal" or "high" values as you prefer.

Water Content (or emulsification) is also an important factor when considering the effects of weathered oil on system performance. In this version of ROC, water content values activate "alert" messages when they reach values which in general might significantly impact the efficient recovery/transfer, burning and chemical dispersal of oil, recognizing, however, that a specific system being simulated may work well beyond that value. User Alerts will be displayed at the top of the report accessed by the "Report" tab. The number of user alerts for the simulation is displayed at the upper right corner of the Report tab.

ROC is currently set to suspend weathering and spreading at an average thickness of 0.001 in.

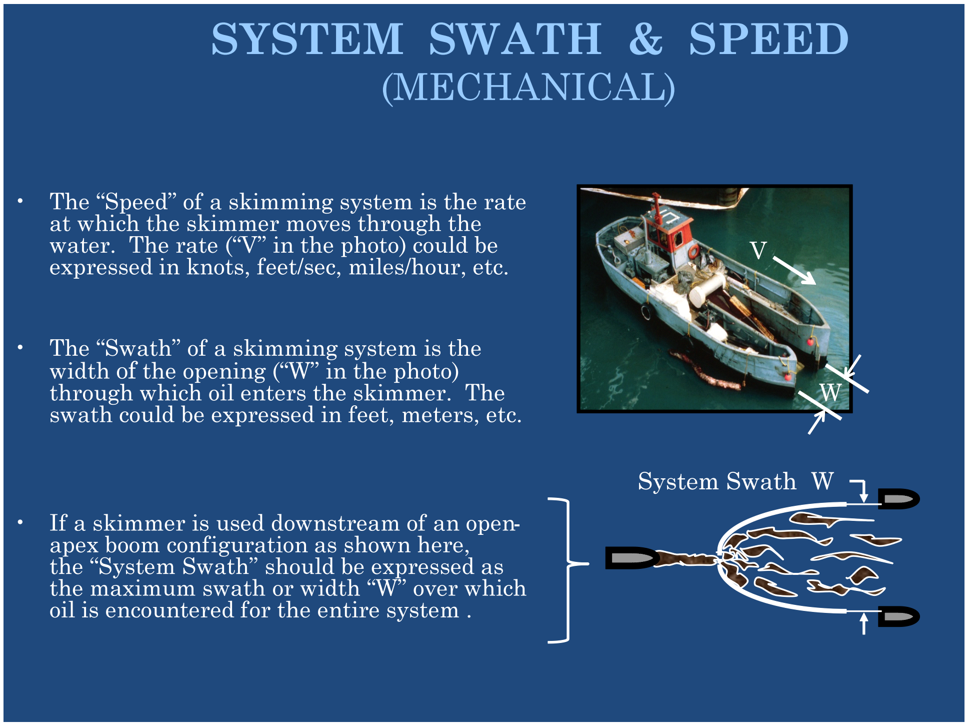
## The ROC Cycle

ROC simulations are defined by the interval between the start date and time and the stop date and time with durations of up to five days.  During a simulation, oil will weather every hour (unless ROC weathering is off), however by default, response is only allowed during periods of daylight (users can override this default).  ROC calculates times of sunrise/sunset based on date and the position of the simulation on the earth.  As response activity removes oil, this volume is subtracted from the remaining volume at hourly intervals called Calculation Intervals.  In this way oil is removed from the environment by natural weathering as well as by response.

## Skimming Systems

A skimming system as used in this document is presumed to be advancing and is composed of:

- A mechanism to encounter oil such as an opening in the bow of the skimmer, boom configured as a  “J” with one end attached to the skimmer and the other end held out to create a swath with a rigid arm or a boom boat, etc.
- A mechanism to transfer fluid onto the skimmer such as a belt, brush, wier pump, etc.
- Storage onboard the skimmer to hold recovered fluids.




Skimming systems can be selected from the library of systems in ROC, new systems can be created, or the parameters for existing systems can be edited for the user scenario. Note that the library of ROC systems cannot be changed permanently. User created or edited systems can be retained as part of a ROC Save File. The Save File will include all aspects of the scenario including dates, environmental settings, oil settings, and response system settings. When a ROC Save File is reloaded, the scenario can be changed, for example, new dates, oil type, etc. The library of response systems will include the standard ROC library plus any systems added by users which can be assigned or "turned off" as desired in the new scenario. ROC Save Files can be shared with other users via email or other file sharing choices.

Each assigned skimmer in a ROC simulation has its own cycle of operations. ROC keeps track of the status of each skimming system during each hour of the simulation and how long it takes for each phase of operations. The user assigns a start date/time within the envelope of the simulation. The start date/time of each skimmer system is that time at which that skimmer system is on-station at the spill ready to begin active skimming. At start date/time, the skimming system begins to recover oil/emulsion which has an average thickness for that hour as derived from the weathering module (unless the user has elected to provide a constant thickness). The initial recovery rate depends on this thickness, the swath of the system, the speed of advance of the system, and the efficiencies assigned to the system. The system will continue to recover until the on-board storage is full or until sunset (or the end of the simulation), whichever occurs first. The recovery rate will be recalculated every hour (if ROC weathering is used) based on the new thickness.

Each skimming system will offload to either a shore-based facility or to a water-based storage unit (e.g. a barge). If it is a barge, the arrival date/time of the barge is specified by the user. If a skimming system fills its on-board storage for the first offload of the simulation and transits to its offload location before its assigned barge arrives, it must wait to offload until the barge arrives. ROC assumes that after this first critical offload, sufficient secondary storage is available for subsequent offloads. The assigned skimming system will continue this cycle of skim to fill, transit to offload location, offload, transit back to oil slick for every day of the simulation starting with sunrise and ending with sunset. After day one it will start skimming every day at the oil slick at sunrise. Note that ROC allows skimming systems to transit and offload during hours of darkness.

The total fluid volume that a skimming system recovers can include oil, stable emulsion, and free water.

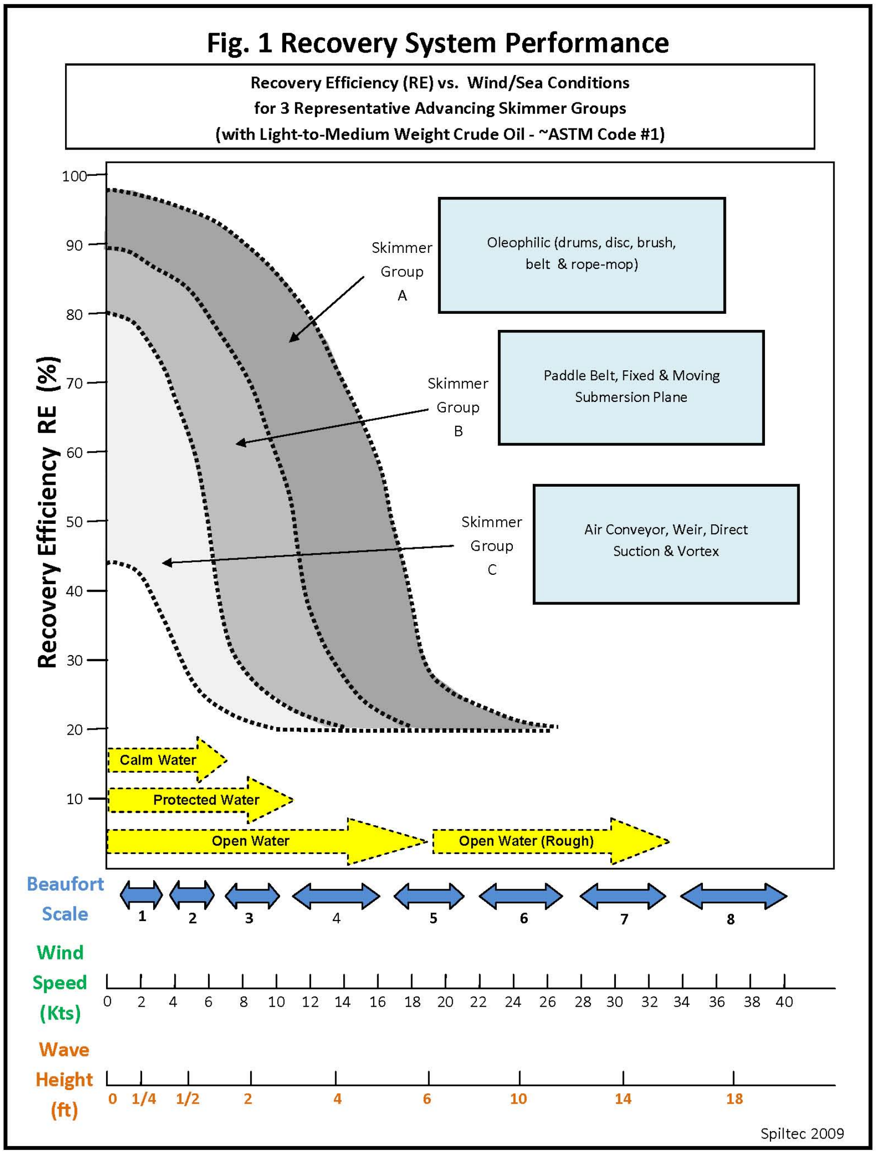
Throughput Efficiency (TE) is the percent oil or stable emulsion recovered onboard the skimmer from the volume of oil or stable emulsion encountered. The ROC default value for TE for both skimming and collection of oil for burning is 75%.

Skimmer Recovery Efficiency (RE)

Recovery Efficiency (RE) is the percent oil or stable emulsion in the total fluid volume recovered onboard the skimmer. For example, if the total volume a skimmer recovers half oil/emulsion and half free water, then RE = 50%.

ROC estimates Recovery Efficiency based on tank tests and field trials for recovery systems that are often difficult to categorize, i.e., there may be a combination of recovery modes within a single skimming system. Such tests/trials also fail quite often in providing important information on oil type and thickness while skimming, speed of advancement, wind/wave conditions, etc. The user of ROC is urged to use these efficiency plots simply as rough approximations for a given system when more accurate information is unavailable.

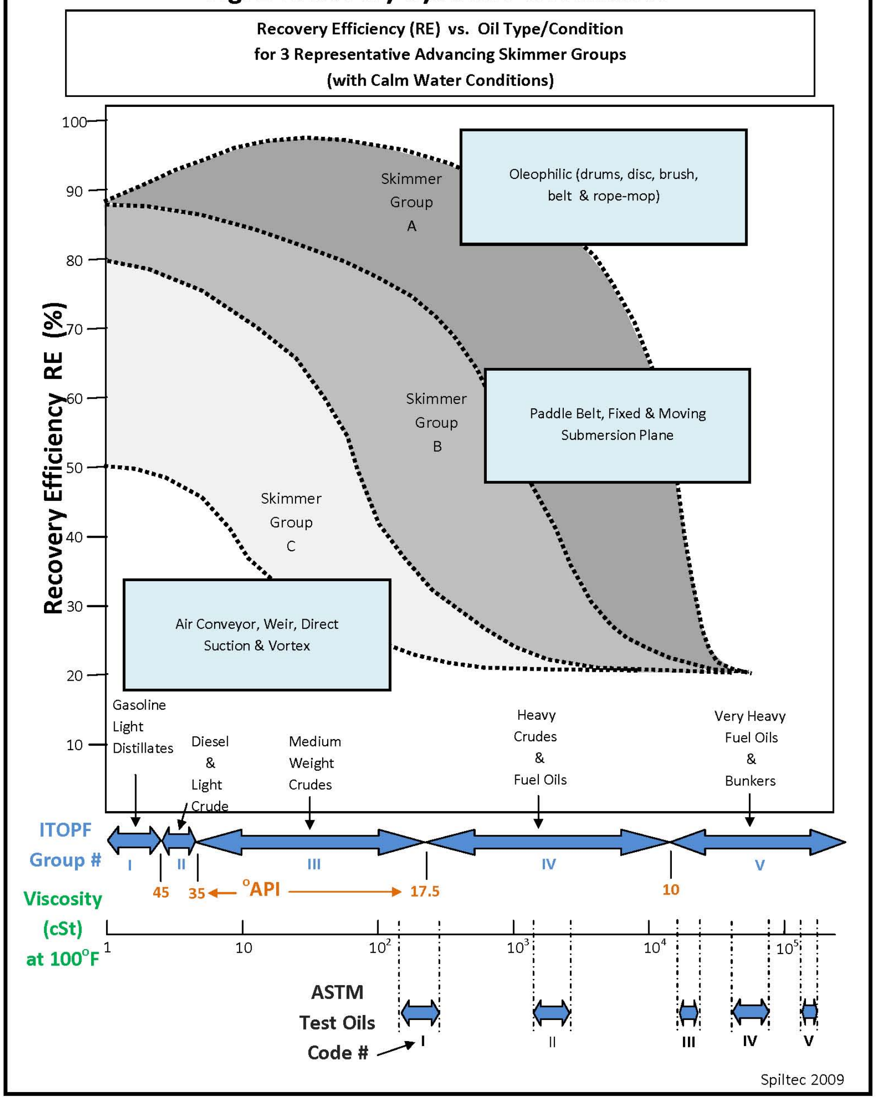
Figure 1 is the ROC Recovery Efficiency vs. Wind Speed for different groups of skimmers. Within each group ROC estimates RE as high, medium, or low. Note that each skimmer group includes a range of skimmer types. There are specific skimmers within each group, which if operated carefully under certain environmental conditions, could easily fall outside of the range suggested in these efficiency plots. User entered values for Recovery Efficiency will override ROC estimates.




ROC also estimates Recovery Efficiency as a function of the oil type/condition and the skimmer group, as shown in Figure 2 below. To use the diagram, (1) look at the bottom of the diagram for the group number, pour point, viscosity, or ASTM code of the spilled oil, then (2) look directly above that point to see the range of estimated recovery efficiencies for the three skimmer groups. For example, for a Group B skimmer operating in calm water (the middle band in the diagram), when diesel oil or a light crude oil has spilled, estimated recovery efficiency may range from about 70 to 85%. For the same skimmer, when a heavy crude or fuel oil has spilled, estimated recovery efficiency may range from about 20 to 75%, depending on the viscosity of the oil and environmental conditions.

To arrive at a RE for a skimming system for a specific scenario calculation interval, ROC compares the RE vs. Wind with the RE vs. Viscosity and uses the lesser of the two.

**Fig. 2 Recovery System Performance**




Skimmer Equations (Link to ROC skimmer code - Code\response\systems\mechanical\MechanicalSystem.as)

Oil/Emulsion Encounter Rate (EnR) for all response systems has been given above as Equation (1) and is reproduced here:

EnR [gallons per minute] = 63.13 x t [inches] x w [feet] x v [knots]

The Oil/Emulsion Recovery Rate (ORR) is the volume of oil/emulsion recovered onboard the skimmer per unit time.

ORR [gal/min] = EnR [gal/min] x TE/100 (2)

The Total Fluid Recovery Rate (TFRR) is the volume of oil/emulsion plus the volume of free water recovered onboard the skimmer per unit time. The Oil/Emulsion Recovery Rate may also be expressed as:

$$ORR\ [gal/min] = TFRR\ (gal/min) \times RE/100 \qquad (3)$$

$$\text{therefore, } TFRR = EnR \times (TE/RE) \qquad (4)$$

The limiting rate to the TFRR is the rated pump rate (PR) or nameplate pump rate of the system. The nameplate pump rate or Maximum Pump Rate (MaxPR) for recovered oil/emulsion and free water (allowing for viscosity and gravity or "head" losses) must be greater than or equal to the TFRR. If the TFRR exceeds the nameplate pump rate, TE is recalculated by the formula:

$$TE = MaxPR \times RE/EnR \qquad (5)$$

Note: It would also be possible to bring the Max PR in line with the TFRR by reducing the skimming speed and/or swath width.

The maximum effective swath (Max Swath) for a given skimming system operating on a specified slick thickness can be determined by substituting MaxPR for TFRR and solving for swath (w) in equation (5):

$$Max\ Swath\ [ft] = MaxPR\ [gal/min] \times RE\ /\ 63.13 \times v\ [knots] \times t\ [inches] \times TE \qquad (6)$$

Note that the computed maximum effective swath may be operationally impossible to achieve.

Decanting of recovered free water will be a factor in the time to fill onboard storage. If decanting is not occurring (i.e. recovered free water is retained in onboard storage (OnBoardStorage), then the Time to Fill ($t_f$) is given by the following expression:

$$t_f[hours] = 0.7 \times OnBoardStorage\ [bbl]/TFRR\ [gal/min)] \qquad (7)$$

The Time to Fill in decant mode (all or a portion of the recovered free water is separated and discharged back into the water ahead of the recovery system) is:

$$t_f[hours] = 0.7 \times OnBoardStorage\ [bbl]/(ORR + WRR)\ [gal/min] \qquad (8)$$

where:

$$WRR = \text{Water Retained Rate} = (1\text{-}RE) \times TFRR \times (1\text{-}\%Decant) \qquad (9)$$

Skimmer Alerts

Under certain conditions, skimmer performance is impaired or not possible. If the total fluid recovery rate exceeds the nameplate pump rate, the throughput efficiency is recalculated by formula (5) and the following message is displayed in the first section of the Report Tab: "Total Fluid Recovery Rate is greater than Nameplate Pump Rate, recalculating Throughput Efficiency."

If the wind speed for a Calculation Interval is greater than 19 knots the skimmer becomes inactive and the following message is displayed in the first section of the Report Tab: "Wind speed too high to operate mechanical system."

If the viscosity for a Calculation Interval is greater than 50,000 centistokes the skimmer becomes inactive and the following message is displayed in the first section of the Report Tab: "Viscosity too high to operate mechanical system."

If the calculated Throughput Efficiency goes to zero the skimmer becomes inactive and the following message is displayed in the first section of the Report Tab: "Unable to operate at throughput efficiency of 0%."

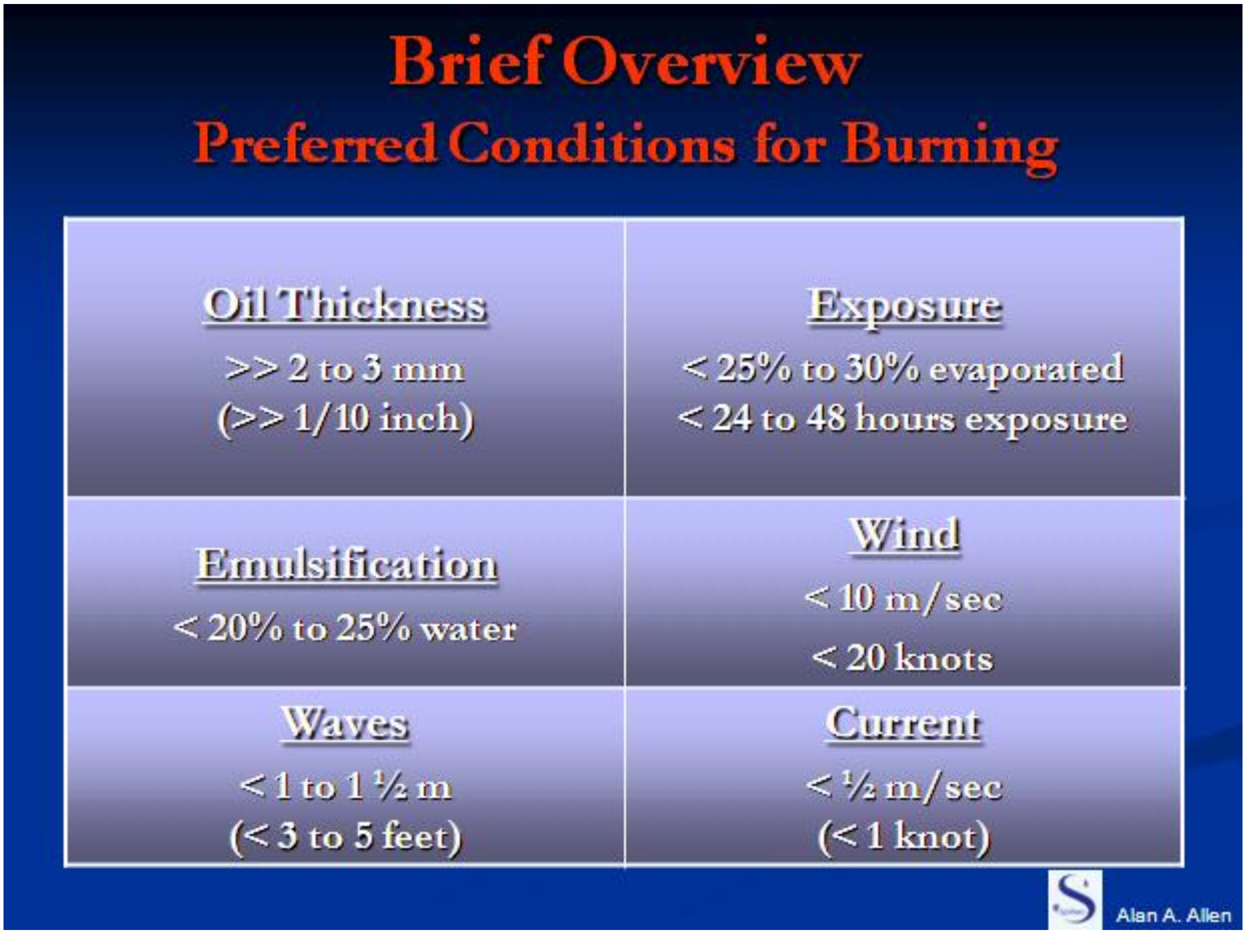
If the calculated recovery rate is not greater than zero the skimmer becomes inactive and the following message is displayed in the Report Tab: "Unable to operate at current wind speed or oil viscosity."

*In-Situ* Burn (ISB) Systems

When an oil slick is relatively thick, fresh and not emulsified, and wind and sea conditions not too high, controlled "in-situ" burning can be used to eliminate large volumes of oil quickly and efficiently. Controlled *In-Situ* burning of oil in open water is conducted in several phases. The oil/emulsion must first be concentrated to a thickness that will support combustion. When used in a "chase-down" mode to intercept an oil slick, two towboats tow a length of fire-resistant boom through the slick to collect oil for a subsequent burn.

The default for collection of oil for burning is during daylight hours only. Collection is terminated at sunset or end of simulation. Towing of boomed oil to burn location and burning can occur after sunset or end of simulation.

The following diagram illustrates preferred conditions for *in-situ* burning of oil offshore.



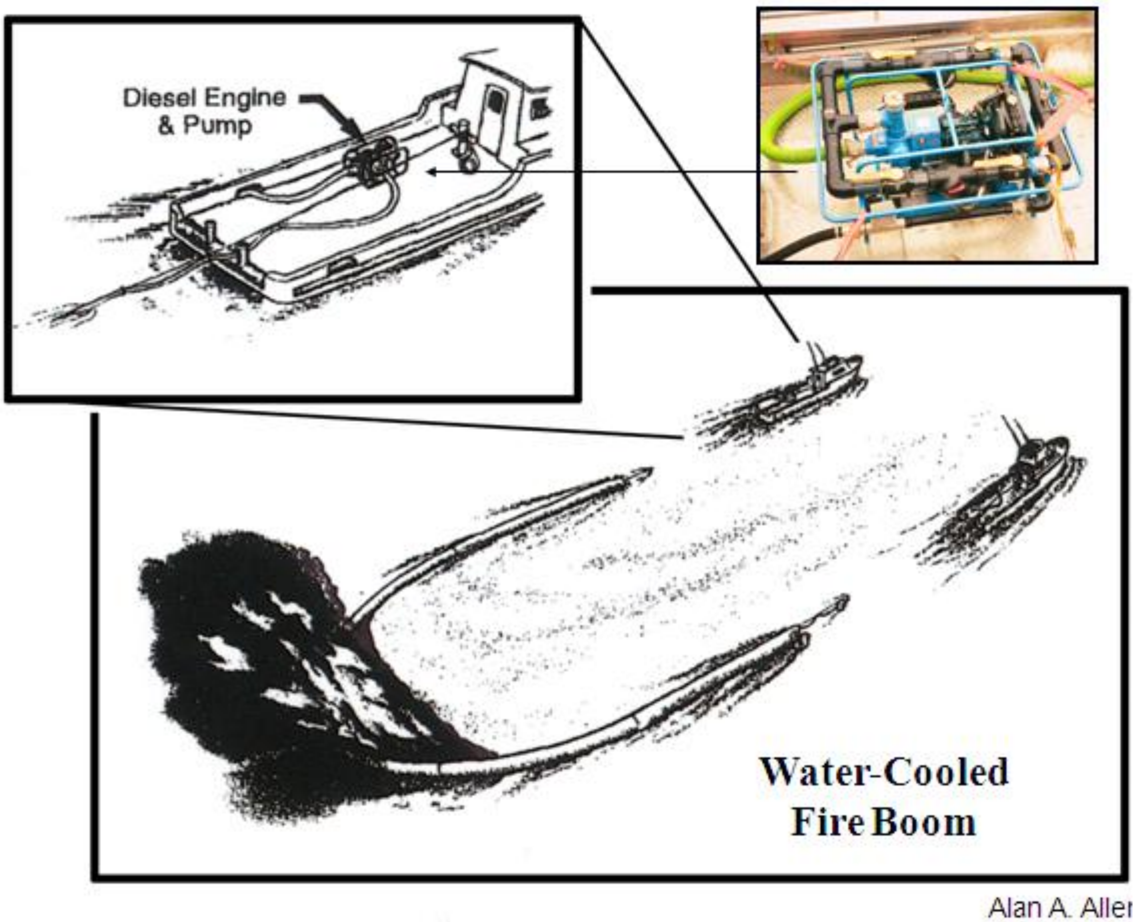

The oil in the boom may need to be moved away from the source prior to ignition to maintain control. When the boom approaches its holding capacity, the boats tow the collected oil a safe distance from the slick and prepare for ignition. The oil may then be ignited with gelled fuel (commonly with a Heli-Torch) or with a hand-held igniter. Depending upon the condition of the oil (volatility, water content & initial thickness) the burn duration will depend upon the size of the burn area within the boom, which is mostly controlled by the speed of the boom-tending boats.

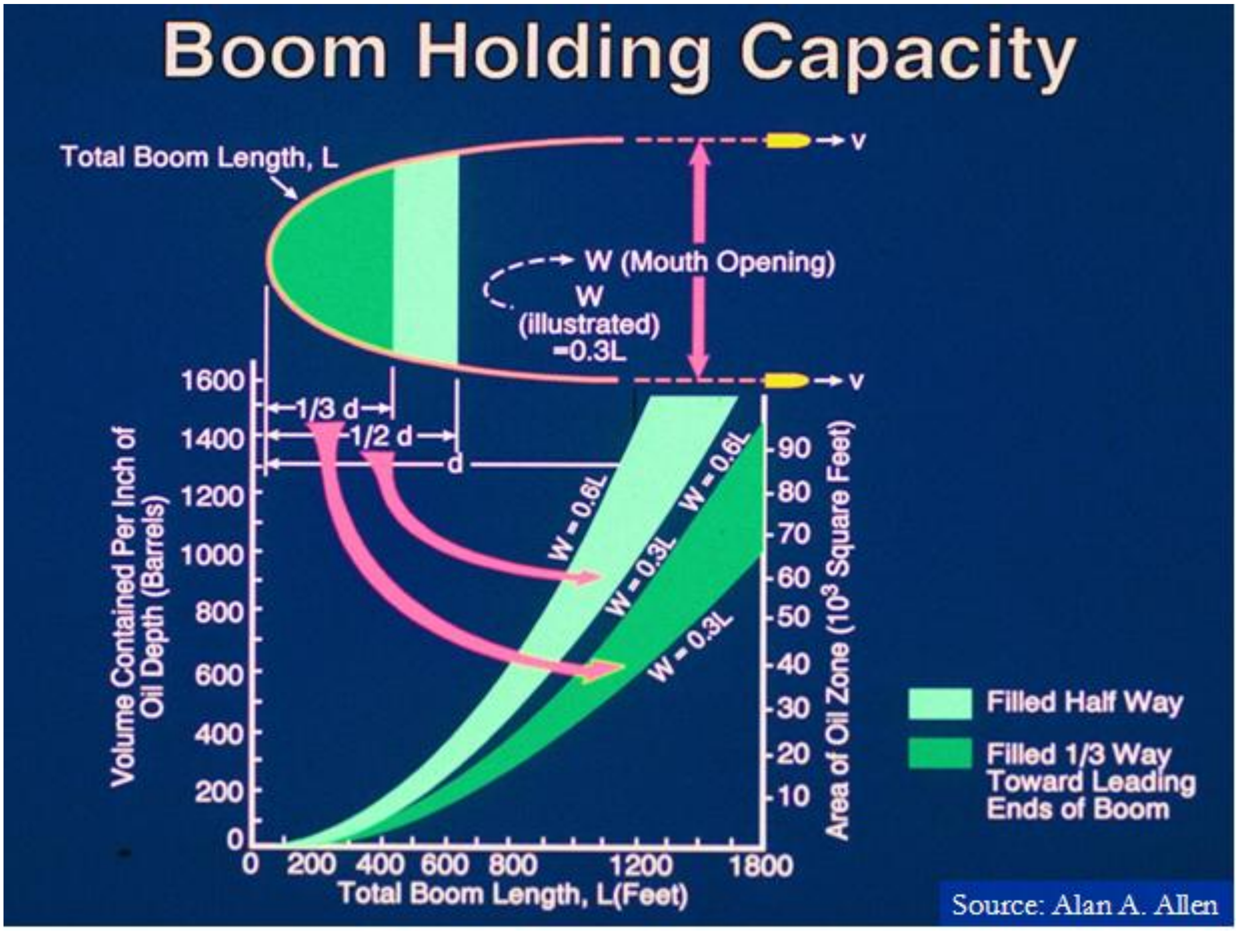
The actual burn rate for a variety of oils is fairly well established from numerous controlled experiments both in the lab, in large tanks, and during field trials. Water uptake in recovered oil and corresponding increases in viscosity may introduce reductions in the rate at which such emulsions burn. The burn rate used in ROC is based on nominal burn rates for light to medium weight "un-emulsified" crude oils. For emulsified oils this rate is reduced in proportion to the water content. The ROC oil burn rate = 0.14 x (100 - % water content)/100.

Burn residue collection from a burn is a separate operation that is not considered in ROC.

Throughput Efficiency (TE) for ISB systems is the amount of oil collected in the fire boom, divided by the amount of oil encountered. TE as a percentage is a measure of the amount of oil retained from that which was encountered during the collection phase. Losses due to entrainment and splash-over during the burning phase are not accounted for in ROC as speeds during burning would normally be well below 3/4 knot with little, if any, significant loss of oil. The ROC default value for TE for both skimming and collection of oil for burning is 75%.

The ROC library does not contain defined systems for ISB. Typically, an ISB system will consist of two tow boats, each with a bridle connected to the ends of a length of fire boom. ROC needs only the length of fire boom and its draft to define a “system”.






<u>*In-Situ* Burn Efficiencies</u>

Burn Efficiency according to ASTM Standard F 1788-97 (Reapproved 2003), is the percentage of the oil removed from the water by the burning, or, the volume of oil before burning; less the volume remaining as a residue, divided by the initial volume of the oil.

Figure 3 below is the ROC Burn Efficiency vs. wind/sea conditions.

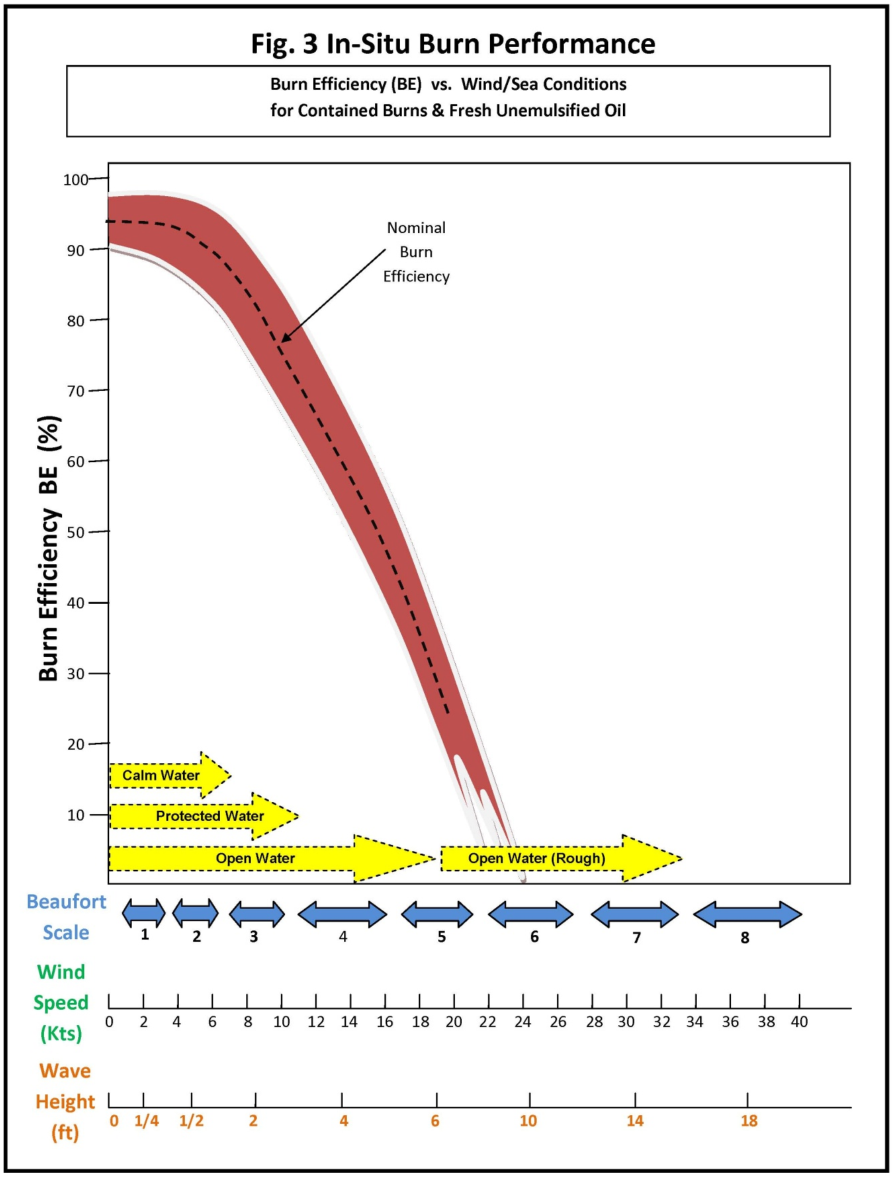
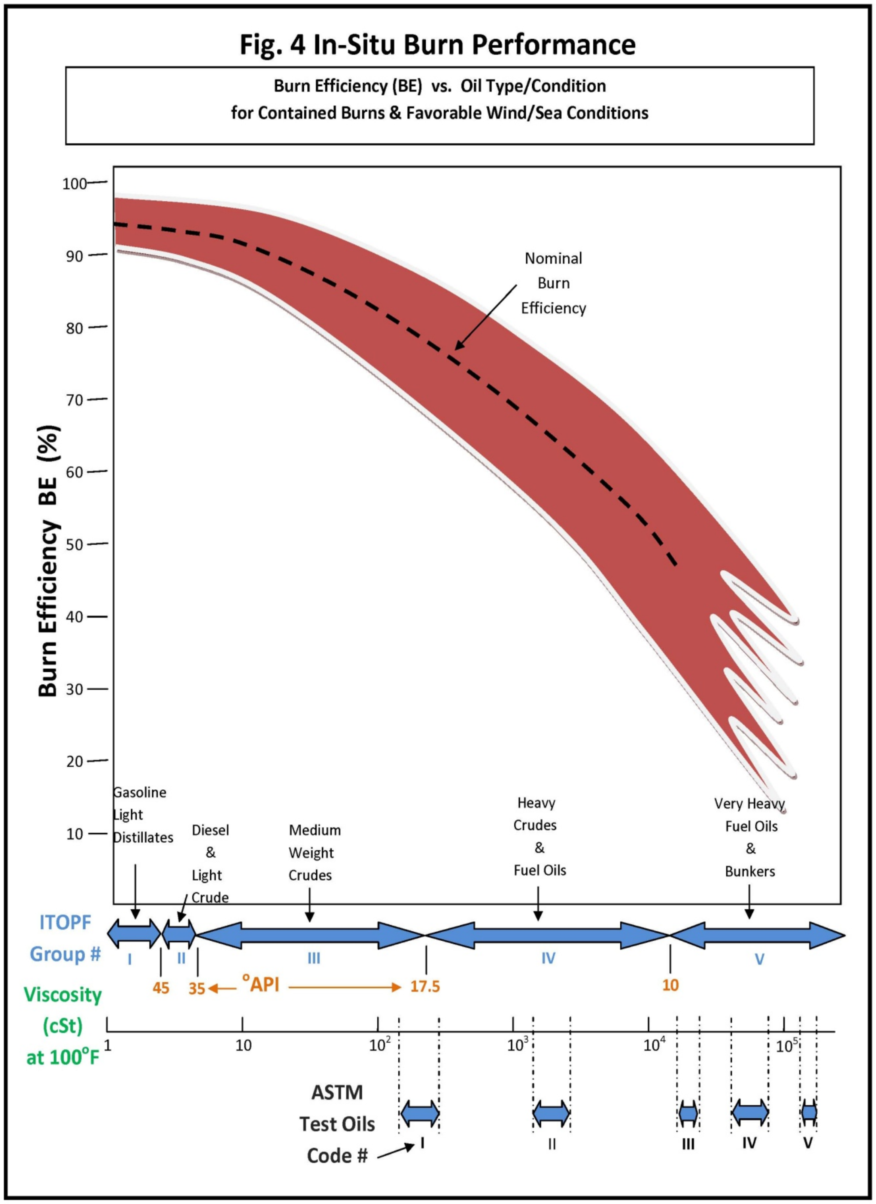



Figure 4 below is the ROC Burn Efficiency vs. oil type/condition.




*In-Situ* Burn Equations (Link to ROC ISB Code – Code\response\systems\burn\BurnSystem.as)

Oil/Emulsion Encounter Rate (EnR) for all response systems has been given above as Equation (1) and is reproduced here:

EnR [gallons per minute] = 63.13 x t [inches] x w [feet] x v [knots]

The length of fire boom is typically given in multiples of 50 feet from 50 to 1000 feet. Swath Width is defined (as per the diagram above) as 3/10 boom length.

Burn Area (1/3 full boom as in diagram above) for a given length of boom is derived from a parabolic equation that was modified to fit values derived by Al Allen (Spiltec) from aerial photos of towed boom.

The oil holding capacity of a boom is determined by its length and draft. The maximum holding capacity of a boom is reached when the average thickness of oil in the boom is approximately 1/3 of the draft of the boom. Collection of oil beyond this thickness may cause loss through entrainment.
Capacity of Boom [cubic feet] = boom draft [in] x boom area [sq ft] x 0.02775 (10)

ACR [acre/min] = Swath Width [feet] x Tow Speed [kts] / 430 (11)

The time to fill a boom to capacity is:
Time to Fill [min] = Capacity of Boom [cubic feet] x 7.48 x TE / EnR [gpm] (12)

The filled boom is sometimes towed away from the collection site an offset distance for safety before ignition. The offset time is given by:
Offset Time [min] = Tow Speed [knots] x 101 / Offset Distance [feet] (13)

ROC uses a burn time that is a function of the thickness of oil in the boom and the degree of emulsification of the oil.

Burn Rate [inches per min] = 0.14 x (100 - % water content)/100 (14)

Burn Time [minutes] = Boom Draft [inches] x 0.33 / Burn Rate [inches per min] (15)

*In-Situ* Burn Alerts

ROC issues User Alerts for high emulsions. The User Alerts are displayed in the first section of the Report Tab and are as follows:
If the % water content > 25% - "Water content could make ignition of the emulsion difficult".
If the % water content > 35% - "Water content is likely to make ignition of the emulsion difficult to impossible".
If the % water content > 50% - "Water content is highly likely to preclude successful ignition of the emulsion".
If the % water content > 70% - "Burning of the emulsion is impossible, setting Burn Efficiency to zero". The burn system becomes inactive.
Other User Alerts come into play when wind speeds or oil viscosities are high:
If the wind speed > 24 knots "Wind speed too high to operate burn system". The burn system

becomes inactive.
If the viscosity > 100,000 centistokes "Viscosity too high to operate burn system". The burn system becomes inactive.

Dispersant Application Systems

ROC provides performance estimates for both vessel and aerial dispersant application systems. As with skimming systems, ROC has a library of dispersant application systems or platforms that can be edited or added to. The ROC dispersant platform database is the same as that developed for the Dispersant Mission Planner 2 (DMP2). Unlike skimming systems or *in-situ* burn systems that begin their cycle of operations at the oil slick ready to operate, dispersant systems begin their cycle of operations at a staging area where they can load dispersants and refuel. Staging areas for aircraft will typically be airports within reasonable range of the spill site and with runways able to handle the load of a fully fueled, dispersant loaded aircraft. Staging areas for helicopters and vessels are not as restrictive as they could realistically even replenish dispersant supplies from a barge in the vicinity of the oil slick.

A sortie for a dispersant application system includes all the necessary operations to start from the staging area fully loaded with dispersant and fuel, deliver one payload of dispersant and return to the staging area. Time for an aircraft sortie includes taxi time, takeoff time, transit time to oil slick, check in time of 10 minutes with spotters, spray and reposition time, transit time back to staging area, landing time, and taxi time. Time for a sortie does not include dispersant reload time or fuel load time. Time for spray and repositioning time will vary due to length of the spray pass and whether the spraying is unidirectional only or bidirectional. Shorter spray passes and unidirectional spraying results in more U-turns, hence more time.

Unidirectional or “race track” spraying is in one direction only (usually upwind). In the spraying direction, the aircraft makes an approach, sprays for one pass length, makes a departure, makes a U-turn, makes a return leg over the slick without spraying, makes a U-turn, and makes an approach prior to the next spray pass. This continues until the entire payload is delivered or to the stop time (sunset, end of simulation).

Bidirectional spraying is in both directions. The aircraft makes an approach, sprays for one pass, makes a departure, makes a U-turn, and makes an approach for the next spray pass. This continues until the entire payload is delivered or stop time (sunset, end of simulation).

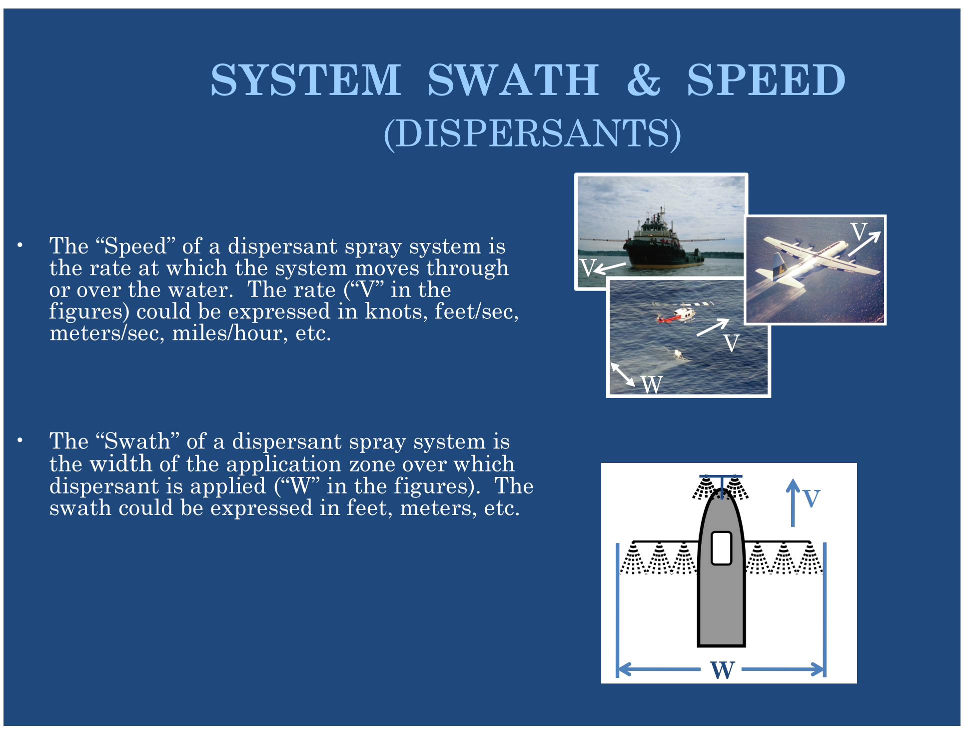
Time for a vessel dispersant sortie includes transit time to the oil slick, spray and reposition time, and transit time back to the staging area. Spray and reposition time can vary depending on whether spraying is continuous or discontinuous. Continuous spraying implies the vessel remains in the oil slick until the payload of dispersant is depleted. Discontinuous spraying occurs within narrower slicks where the vessel turns spraying off while making a U-turn.

## Dosage

It is important to differentiate between desired and achievable dosage. Desired dosage is that determined from the average thickness of the slick and the Dispersant-to-Oil Ratio. The achieved dosage is that delivered by the platform. ROC attempts to do this with the selected swath and application speed and with the calculated pump rate to achieve the desired dosage.

The desired dosage reflects the Dispersant-to-Oil Ratio (DOR) recommended by the dispersant manufacturer, and therefore depends upon the estimated average volume of oil per unit area (or "concentration" of oil) in the slick being treated.

The achievable dosage- the dosage that can be applied- depends on the swath width and speed of the platform, the rate at which dispersant can be pumped from that platform, and other factors. If the slick is thick and the pump rate low, the dispersant system may underdose when applying dispersant. In this case, the achievable dosage may be lower than the desired dosage. An application system with a relatively high pump rate that cannot be adjusted in flight may overdose areas where the slick is relatively thin. In this case, the achievable dosage may be considerably higher than the desired dosage.




The theoretical maximum dosage available from a platform is attained at minimum speed, maximum pump rate, and minimum swath width. The theoretical minimum dosage available from a platform is attained at maximum speed, minimum pump rate, and maximum swath width.

Dispersant Efficiencies

The percent of oil successfully dispersed after any application at sea is extremely difficult to estimate. Such efficiencies are usually only rough qualitative assessments such as: poor, modest, or good. An experienced observer may use terms such as: "no obvious dispersion", "Slow or Partial Dispersion", or "Rapid Dispersion". More precise efficiencies are obtained from carefully controlled experiments in the lab or at larger test facilities such as Ohmsett. Generally speaking, dispersion is likely to be more successful on light-to-moderate-weight crude oils that are relatively fresh and un-emulsified under at least a light to moderate wind-chop.

Figure 5 is the estimated Dispersant Efficiency vs. wind/sea conditions.

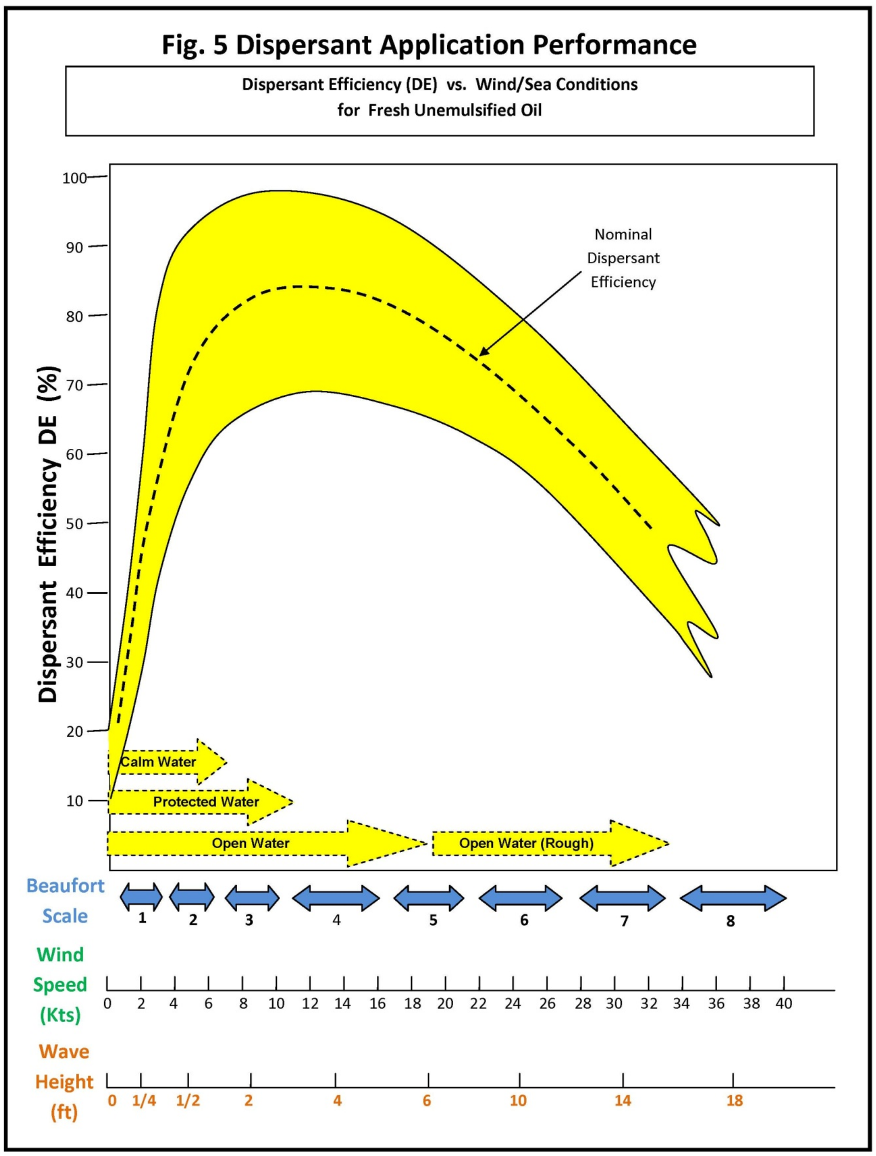
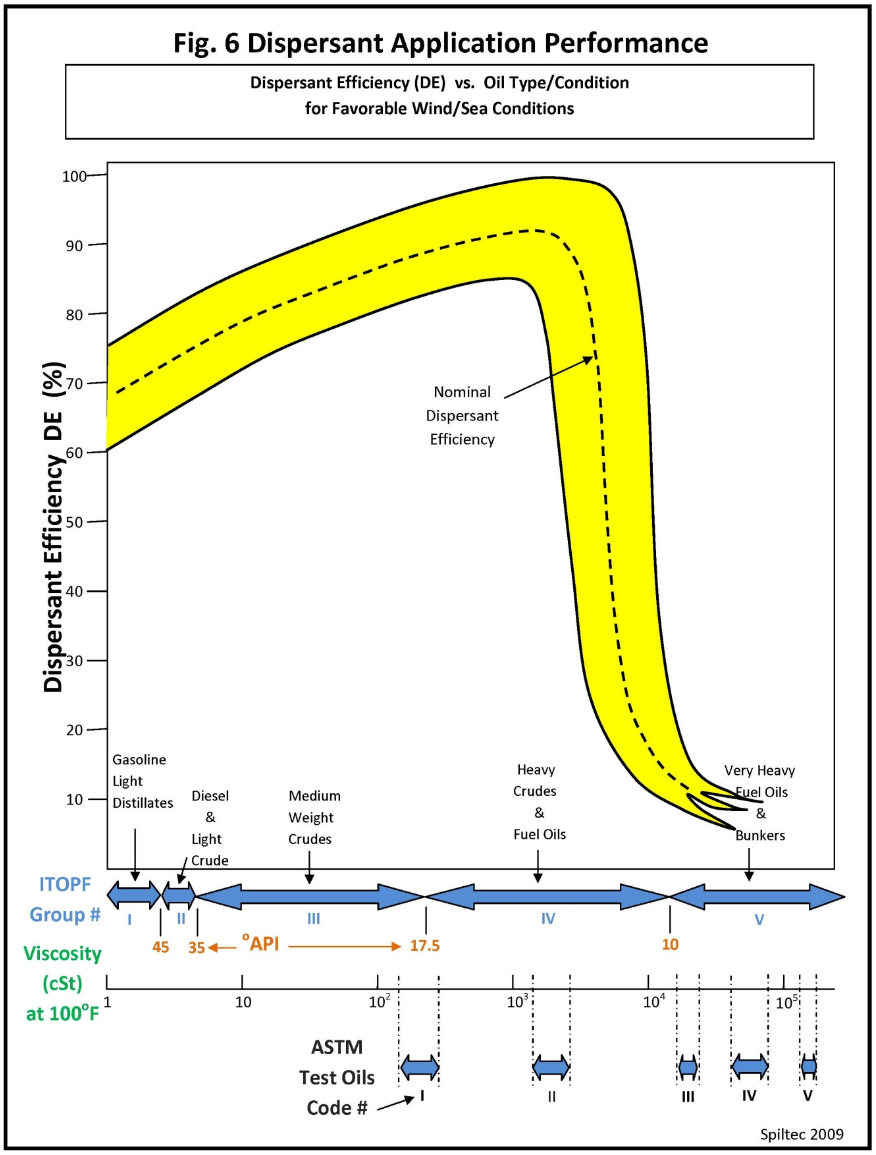


Fig. 5 Dispersant Application Performance

Figure 6 is the estimated Dispersant Efficiency vs. oil type/condition.




## Dispersant Equations

(Link to ROC primary dispersant code – [Code\response\systems\dispersant\DispersantSystem.as ])
Link to ROC aircraft dispersant code – [Code\response\systems\dispersant\DispersantAircraftSystem.as]
Link to ROC vessel dispersant code – [Code\response\systems\dispersant\DispersantVesselSystem.as]

Oil/Emulsion Encounter Rate (EnR) for all response systems has been given above as Equation (1) and is reproduced here:

EnR [gallons per minute] = 63.13 x t [inches] x w [feet] x v [knots]

The Dosage Desired for a given Dispersant-to-Oil Ratio (DOR) is calculated from the slick thickness.

Dosage Desired [gal/acre] = 2.717 x $10^4$ x DOR x Thickness of Slick [in.]) (16)

The Areal Coverage Rate (ACR), while actually spraying, is a function of the Application Speed and the Swath Width.

ACR [acres/min] = Application Speed [kts] x Swath Width [feet] / 430 (17)

The Desired Pump Rate (DesPR) to achieve the Dosage Desired becomes:
DesPR [gpm] = Dosage Desired [gal/acre] x Areal Coverage Rate [acres/min] (18)

When the Desired Pump Rate is within the range of pump rates that the platform can deliver the Desired Pump Rate equals the Achieved Pump Rate.

The Desired Pump Rate to match the Dosage Desired may be greater than the platform can deliver, i.e. with thicker oil slicks. In this case the Achieved Pump Rate will be set equal to the Maximum Pump Rate (MaxPR) of the platform and the slick will be underdosed. The Achieved Dosage will then be:

Achieved Dosage [gal/acre] = MaxPR [gpm] x 430 / Application Speed [kts] x Swath [ft] (19)

For thinner oil slicks the Desired Pump Rate to match the Dosage Desired may be less than the platform can deliver. In this case the Achieved Pump Rate will be set equal to the Minimum Pump Rate (MinPR) of the platform and the slick will be overdosed. The Achieved Dosage is:

Achieved Dosage [gal/acre] = MinPR [gpm] x 430 / Application Speed [kts] x Swath [ft] (20)

Area Treated per Sortie [acres] = ACR [acres/min] x Payload [gal] / Pump Rate [gpm] (21)

The actual spraying time per payload or sortie is given by:

Spraying Time [min] = Payload [gal] / Achieved Pump Rate [gpm] (22)

The spray time per pass is given by:

Spray Time per Pass [min] = Application Speed [kts] / Pass Length [nm] x 60 (23)

The number of spray passes (# of passes) in a sortie is:

# of passes = Spraying Time [min] / Spray Time per Pass [min] (24)

The lesser of the Dispersant Efficiencies from Figures 5 and 6 along with the DOR determine the volume of oil dispersed per sortie (or per payload):

Volume of Oil Treated/Sortie [gal] = DE x Payload [gal] /DOR (25)

Dispersant Alerts

ROC issues User Alerts for high emulsions. The User Alerts are displayed in the first section of the Report Tab and are as follows:

- If the % water content > 25% - "Water content could make chemical dispersion of the emulsion difficult".
- If the % water content > 35% - "Water content is likely to make chemical dispersion of the emulsion difficult to impossible".
- If the % water content > 50% - "Water content is highly likely to preclude successful chemical dispersion of the emulsion".
- If the % water content > 70% - "Chemical dispersion of the emulsion is impossible, setting Dispersant Efficiency to zero". The dispersant system becomes inactive.

For low wind speeds (less than 3 knots) in a Calculation Interval, ROC displays a User Alert in the first section of the Report Tab: “The achieved dispersant efficiency could be very low unless wind speeds increase after dispersant application.”

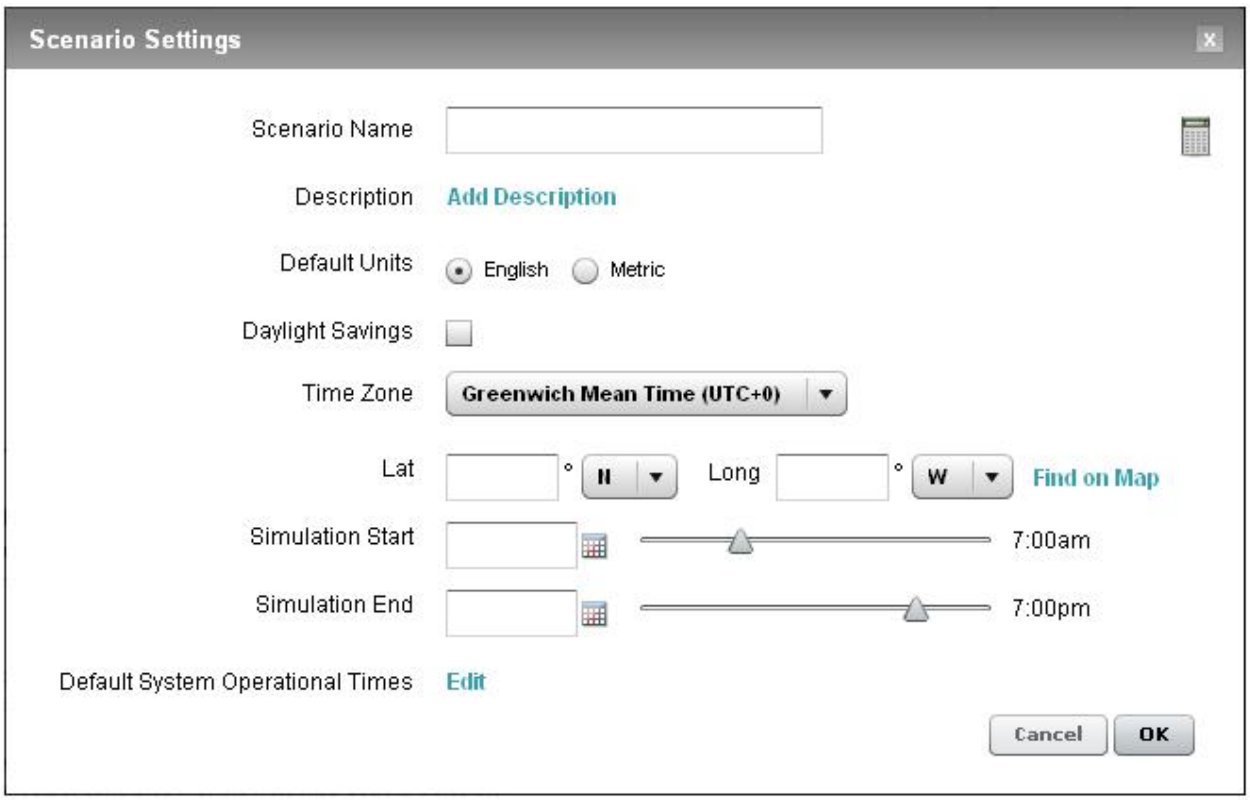
For high wind speeds (greater than 36 knots) in a Calculation Interval, the dispersant system becomes inactive and ROC displays a User Alert in the first section of the Report Tab: “Wind speed too high to operate dispersant system.”

For viscosities greater than 100,000 centistokes, the dispersant system becomes inactive and ROC displays a User Alert in the first section of the Report Tab: “Viscosity too high to operate dispersant system.”

If time on station plus total transit time is greater than the maximum operating time of a platform ROC displays a User Alert in the first section of the Report Tab: “Calculated sortie time is greater than maximum operating time, not able to spray entire payload at specified transit distance.” ROC will then set the time on station = the maximum operating time minus the total transit time. If time on station is less than zero, time on station is set to zero, the dispersant system becomes inactive, and ROC displays a User Alert in the first section of the Report Tab: “Unable to operate with the current maximum operating time.”

The ROC Interface

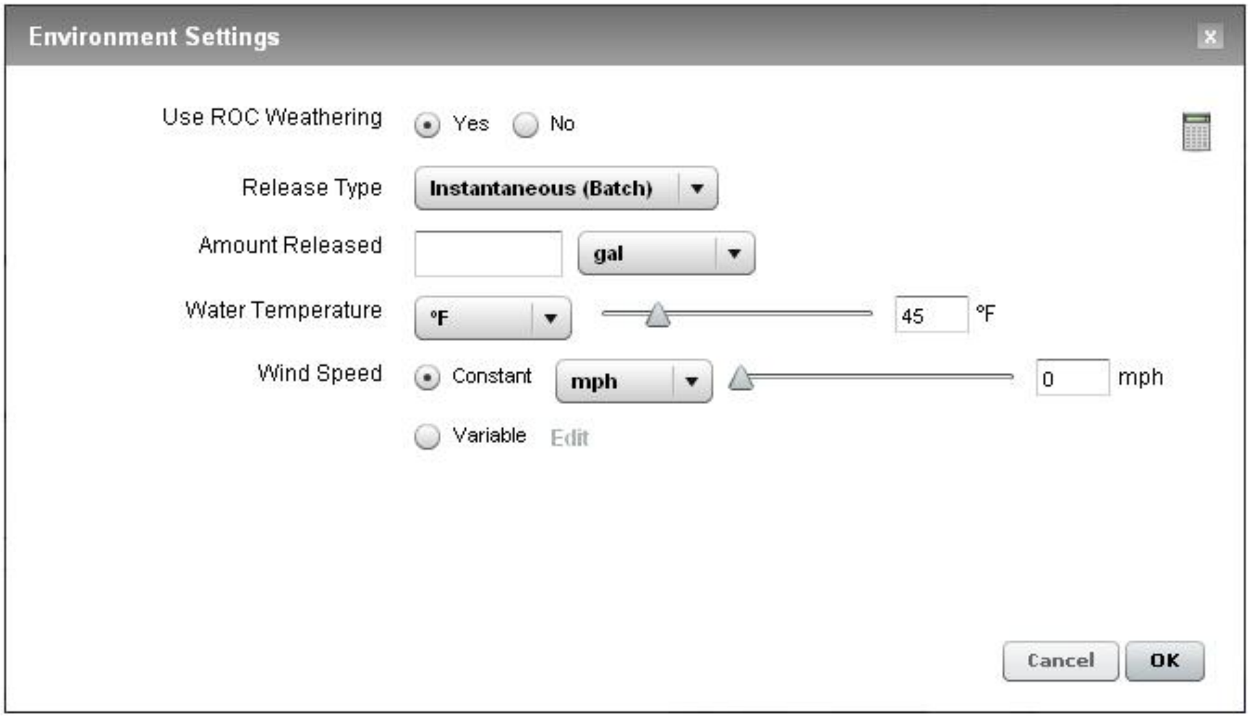
First the response scenario is defined, the environment where the spill takes place, and the type and quantity of oil spilled. Next, the equipment (skimming, dispersant, and in-situ burn systems) deployed in the response are specified. ROC can also open a Save File previously created. As information is entered, ROC will automatically display its estimates, including predicted weathering, mass balance tables and charts, and predicted recovery rates and other data for the response systems selected. Once a scenario is finished, it can be saved as a ROC Save File for later use. Contextual help is displayed when moving the cursor over an input field name. To view more help about a ROC input, click on the field name. This will display ROC main help; a tree-structure of ROC help is on the left pane and extended help and graphics on the right pane. Following are ROC screen shots for user inputs and a discussion of those inputs.



Scenario Inputs

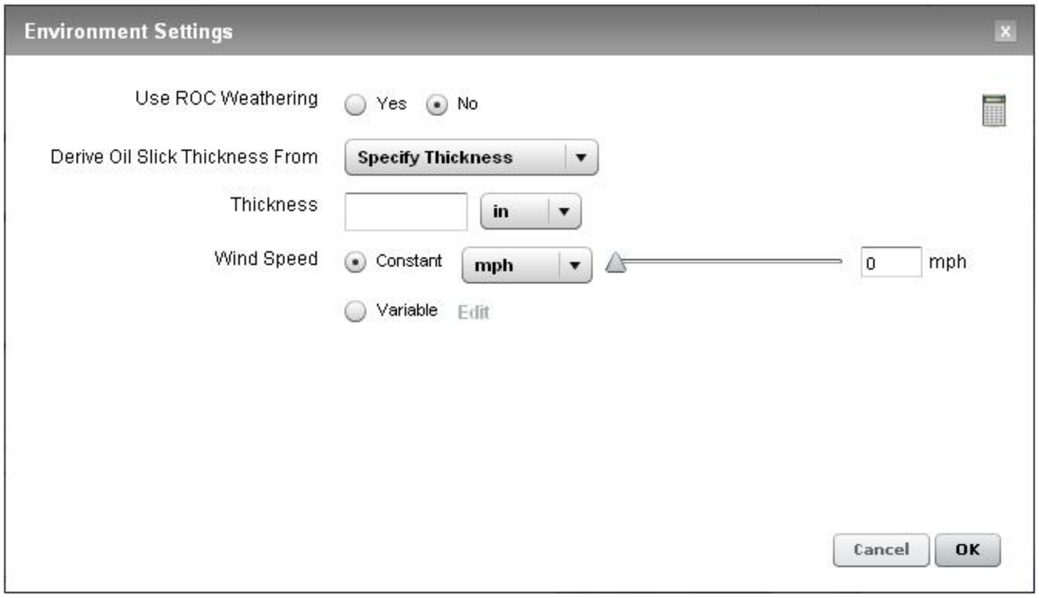
- Scenario Name – Enter a descriptive name for the simulation
- Description – This is optional textual information to capture information for the simulation
- Default Units - Click either "English" or "Metric" units. The units you choose will appear first in ROC's menus, but you'll also be able to see and select other units. If English units are selected, Mass Balance volumes will be displayed in barrels; if Metric units are selected, Mass Balance volumes will be displayed in cubic meters. (Link to ROC Unit Conversion Code - Code\calculators\ConversionCalculator.as)

- Daylight Savings- In the U.S., Daylight Savings Time begins on the second Sunday of March and ends on the first Sunday in November. If the date range of your simulation spans a change in Daylight Savings Time, edit the times of sunrise and sunset manually. To do that, click the Edit link next to Sunrise/Sunset, then adjust the sliders to represent your best estimates of sunrise and sunset times. (Link to ROC Sunrise/Sunset code – Code\calculators\SunriseSunsetCalculator.as)
- Time Zone - Coordinated Universal Time (UTC, previously known as Greenwich Mean Time) is the local time at the prime meridian, which runs through Greenwich, England. Local time at locations east of the prime meridian (Eastern Europe, Asia, Australia) are ahead of UTC and represent a positive UTC offset. Local times west of the prime meridian (North and South America) are behind UTC and represent a negative UTC offset. Daylight Savings Time affects UTC offsets. When your local time moves ahead one hour as Daylight Savings Time begins (on the second Sunday of March in the US), your UTC offset changes. For example, if your UTC offset is -5 UTC, it changes to -4 UTC when Daylight Savings Time begins, and returns to -5 UTC when Daylight Savings Time ends (on the first Sunday in November in the U.S.). If you change the time zone or UTC offset for your simulation after setting the simulation begin and end dates, click "Edit", then click "Recalculate". Sunrise and sunset times don't automatically update when you change Time Zone or UTC offset.
- Lat (Latitude), Long (Longitude) - Sunrise and sunset are used as the default values to define the start and stop times respectively for response during each day of a Simulation Period. Enter your latitude and longitude directly (in whole degrees), or click "Find on Map" to indicate the general spill location on a map. ROC needs your general location to calculate times of sunrise and sunset. ROC does not use the location information for any other purposes.
- Simulation Start - Enter the date and time when the oil first spills into the water. Click on the calendar icon to set the date. Use the slider bar to set the start time. The simulation starts when the oil first spills and begins to weather (not when the response equipment first arrives on scene).
- Simulation End - Enter the date and time when you want your simulation to end. Click on the calendar icon to set the date. Use the slider bar to set the end time. ROC limits simulations to 5 days. A typical simulation for an instantaneous spill in the open ocean might last 3 to 4 days. Over time, the slick spreads and becomes thinner. Eventually, the oil becomes too difficult to recover, generally when the slick becomes too thin to burn, disperse, or collect by skimming. As the slick spreads and thins to approach an average thickness of about 0.02 mm, oil encounter rates for nearly all systems will be quite low. A slick this thin is typically metallic in color. ROC is currently set to suspend weathering and spreading at an average thickness of 0.001 in.
- Default System Operational Times - By default, ROC uses the estimated sunrise and sunset times as the start and stop times for your response systems. That is, it assumes that systems begin collecting or dispersing oil at sunrise, and end at sunset (Day 1 arrival of a system will most likely not be sunrise and will need to be adjusted. You can adjust these default start and stop times for any of the assigned systems. Sunrise and sunset times don't automatically update when time zone or UTC offset are changed.

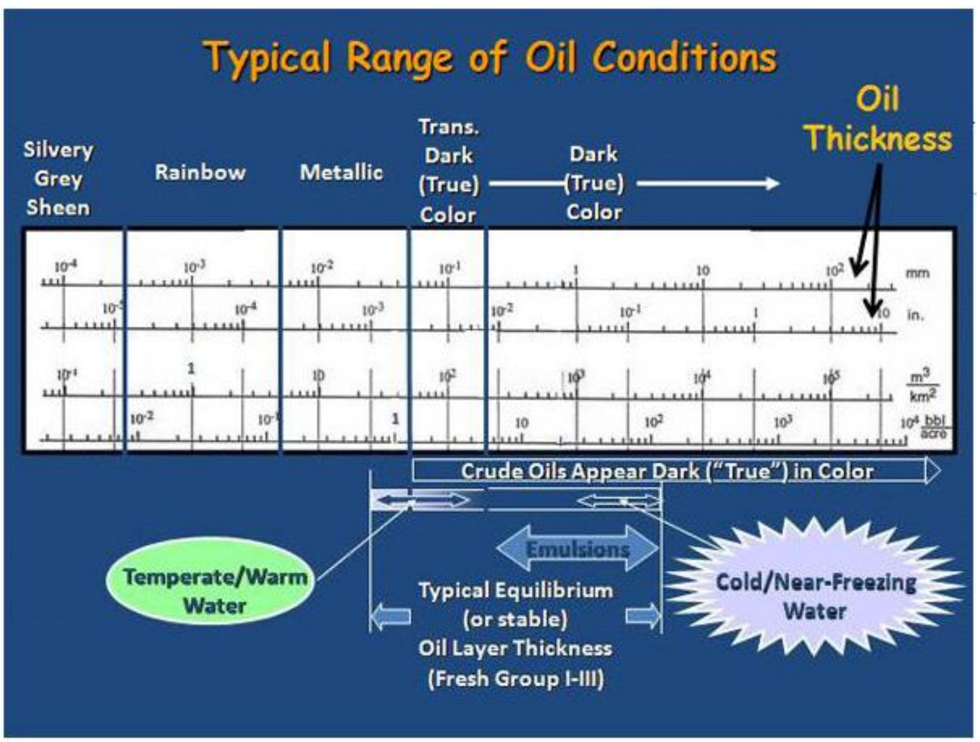



Environment Settings

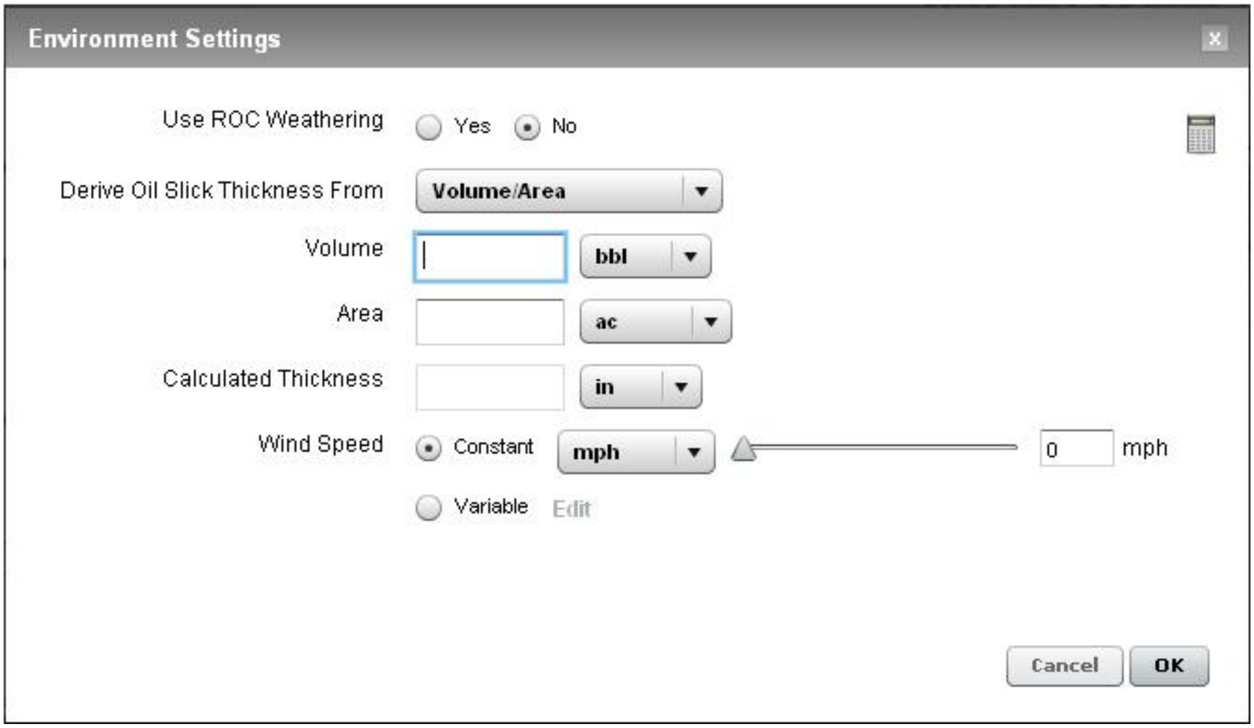
- Use ROC Weathering - The thickness of an actual oil slick changes over time as the oil weathers. Select ROC Weathering to "Yes" to have the Response Options Calculator predict how weathering processes will change slick thickness over time. Select ROC Weathering to "No" to enter your own thickness for the oil slick in three different ways. This thickness will remain constant for the duration of the simulation.



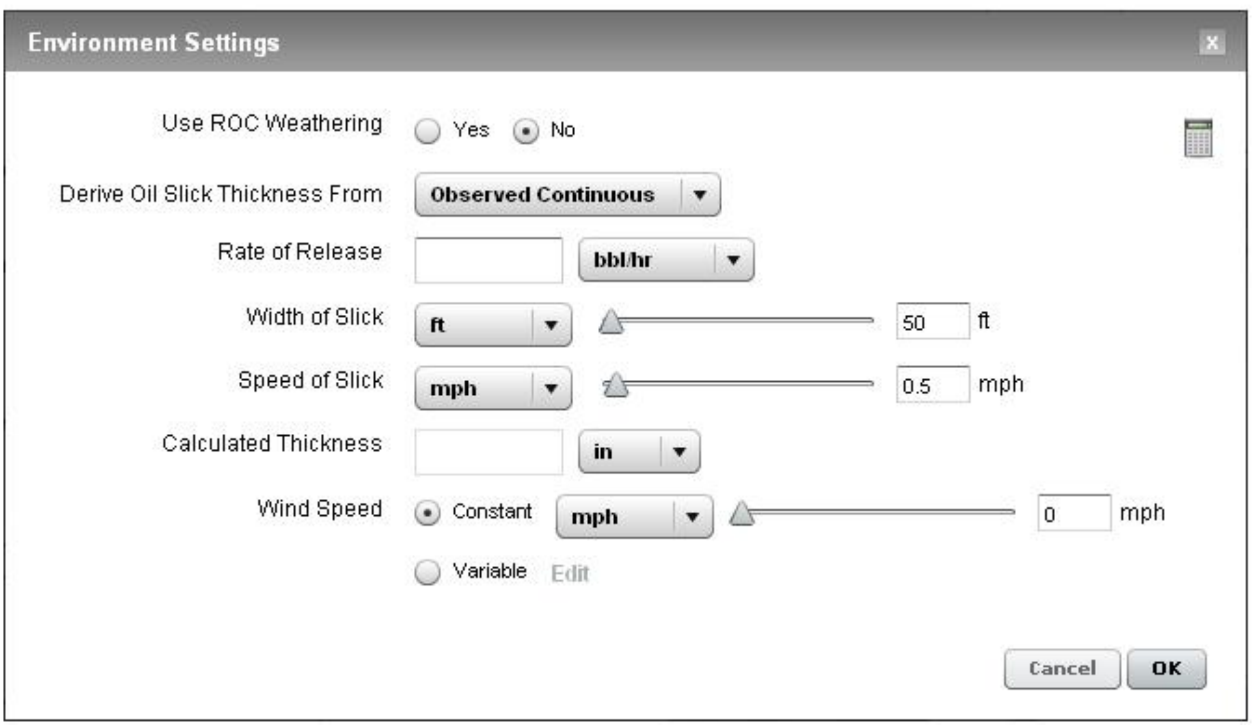

The following graph illustrates thickness ranges for different oil conditions and includes the Bonn Agreement Oil Appearance Codes[4].



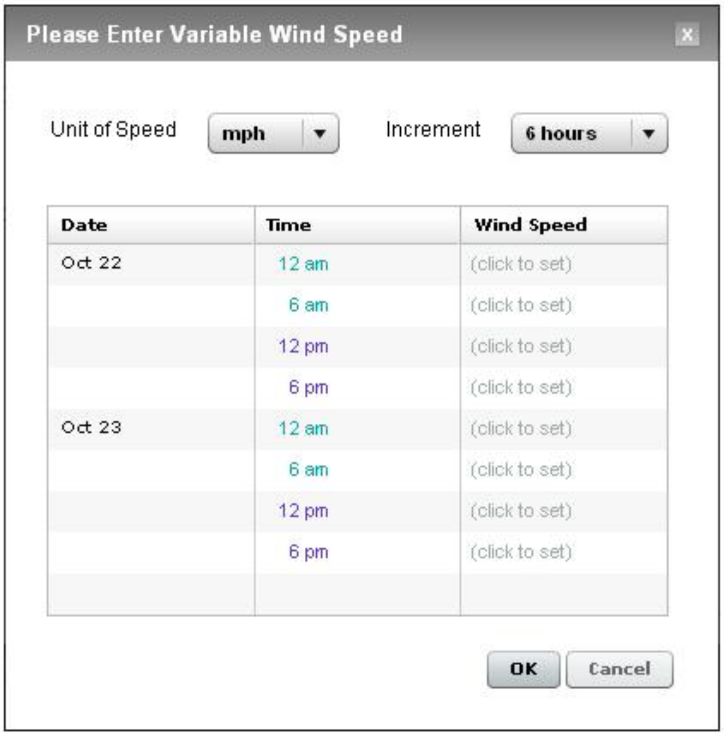

Average thickness can be calculated from known Volume and Area as shown in this screen



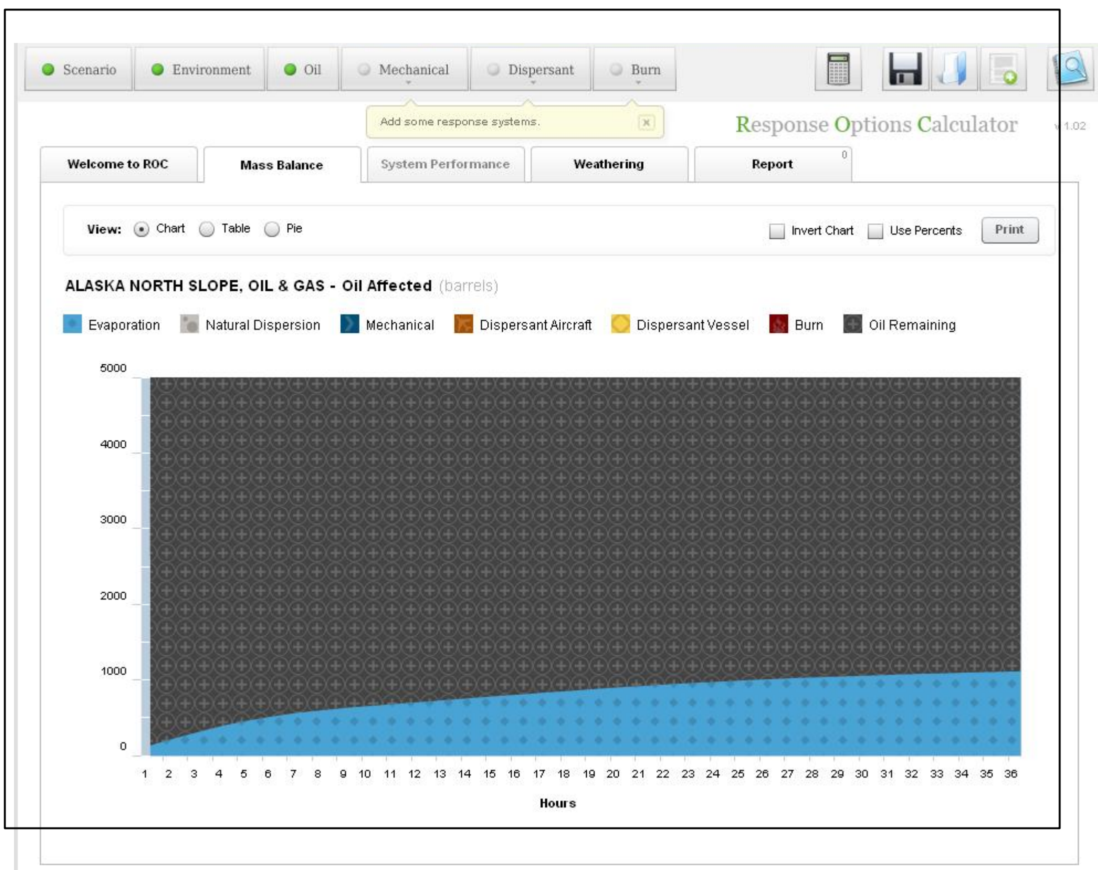

Finally, average thickness can be calculated from an observed continuous release where the rate of release, the width of the slick, and the speed of the slick can be estimated.



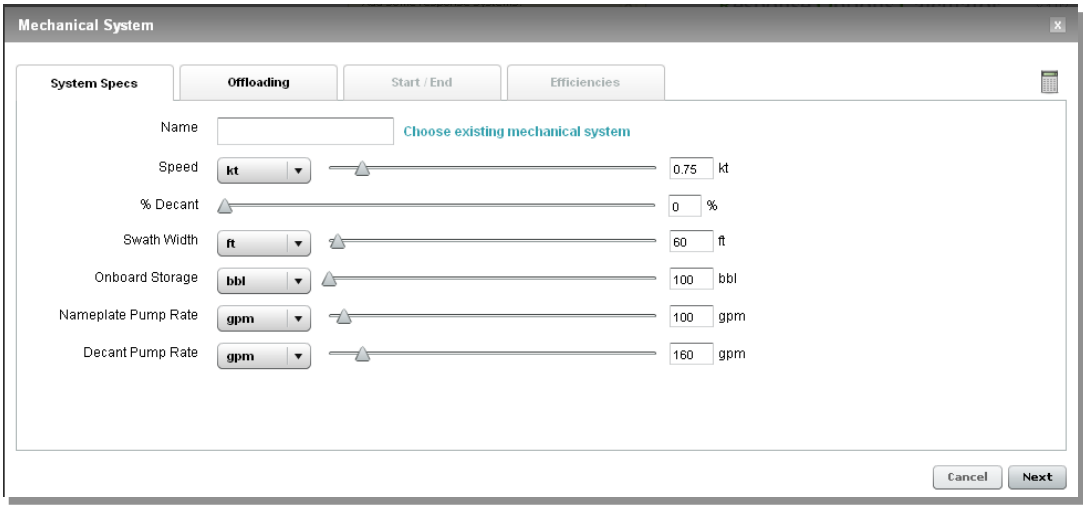

Wind speed can be set to Constant for the simulation or it can be Variable. In Variable select the Wind Speed Units and the time Increment for entries.



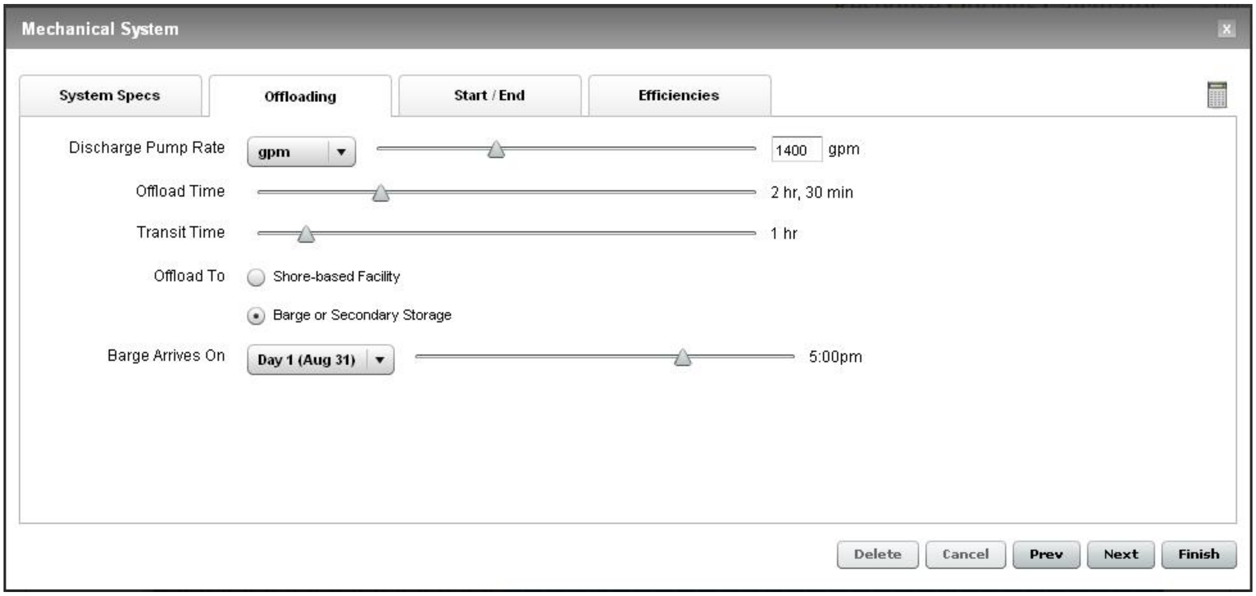

With a Scenario and Environment settings entered, ROC displays Weathering even if no response systems have been assigned.



Skimmer Platforms

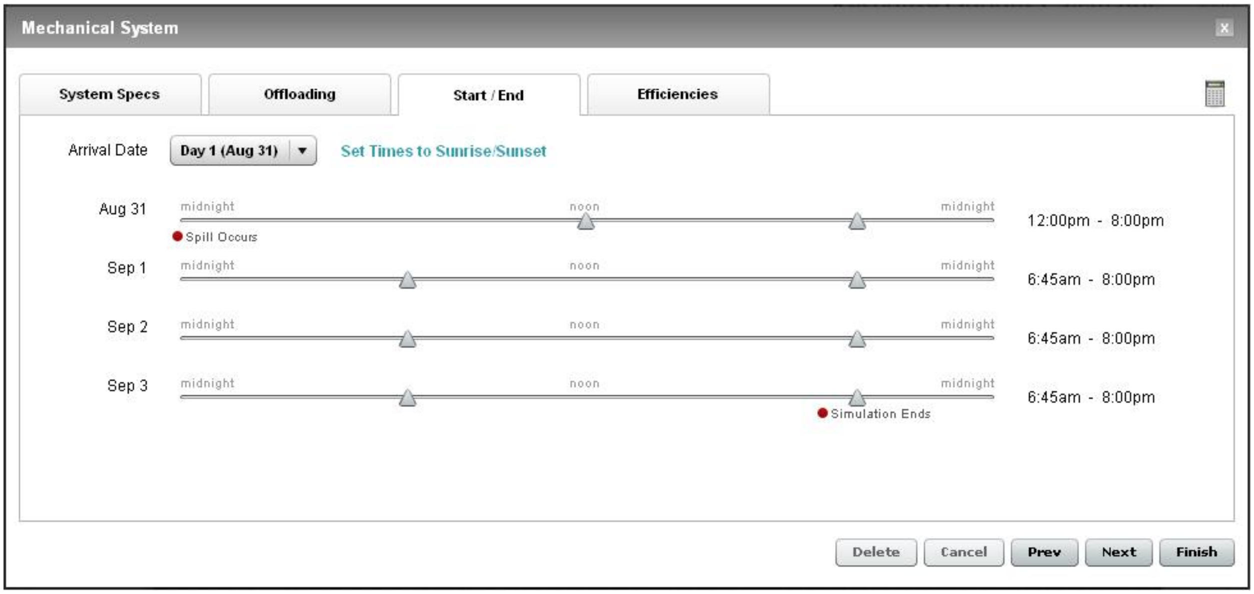



- Name - If adding a new skimmer, enter the Name or click on "Choose existing mechanical system" to view the library of skimmers.
- Speed – Select the Speed units, then use the sliding "thumb" to adjust to the desired value. Alternatively, click in the text box on the right and enter the value directly. Use the speed of the response system with respect to the oil slick.
- % Decant is the percentage of the free water collected that is separated from the total fluids collected and decanted back into the water.
- Swath Width is the width of the system swath, for example, if enhanced skimming is taking place with two boom boats out in front of the skimmer, the Swath Width would be the distance between the boom boats.
- Onboard Storage is the volume of storage aboard or attached to the skimmer where oil/emulsion is stored until it can be offloaded to secondary storage.
- Nameplate Pump Rate may not be a pump rate per se, but the rated capacity of the skimming system as determined by ASTM Guide F631 or equivalent.
- Decant Pump Rate is the rated capacity of the pump used to decant recovered free water. It is used in conjunction with the Decant %, the Total Fluid Recovery Rate, and the Recovery Efficiency, i.e. the computed decant rate. ROC will use the lesser of the two.
- Click on Next to go to the Offloading tab.

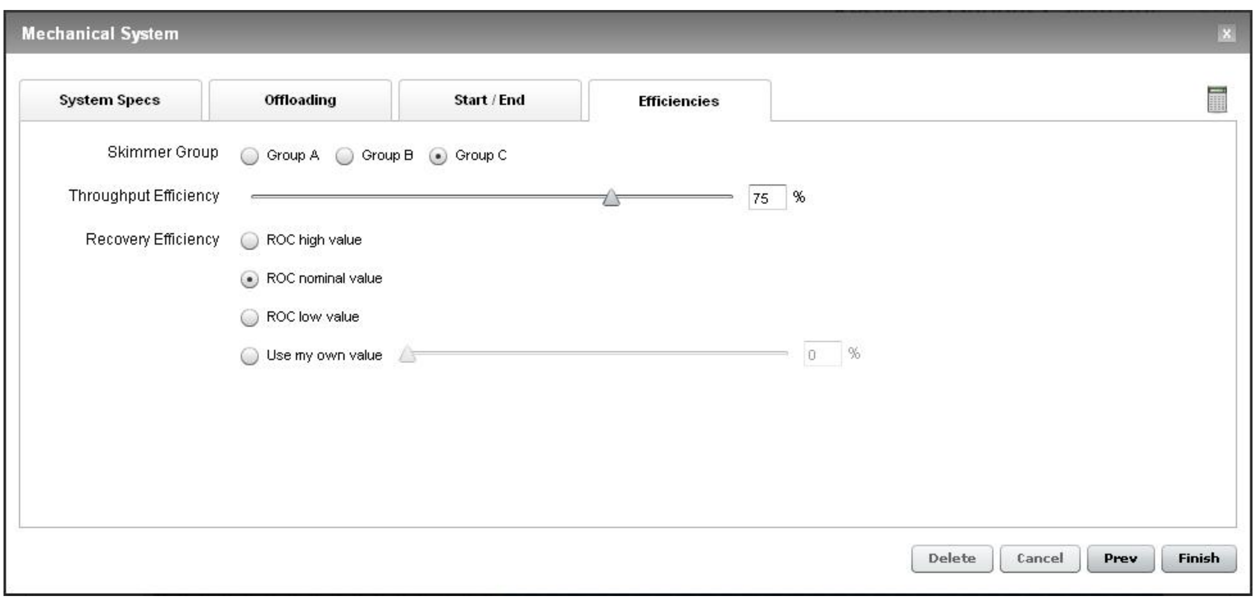



The Offloading tab contains user input related to offloading the filled onboard storage of the skimming system.

- Discharge Pump Rate is the rate at which fluids are offloaded from the skimmer to secondary storage by a pump on the skimmer or on the secondary storage.
- Offload Time includes the time to tie up, hook up hoses, and fill out forms as well as the actual fluid transfer time. ROC will perform an internal calculation using the Onboard Storage of the skimming system, the Discharge Pump Rate, and the Offload Time to insure that the Offload Time is realistic.
- Transit Time is the one-way time from the skimming location to the offloading location.
- Offload To Shore-based Facility, or Barge or Secondary Storage. If Barge or Secondary Storage is selected, the arrival time of the Barge or Secondary Storage needs to be specified. One arrival time, i.e. the same Barge or Secondary Storage can be used for multiple skimming systems.
- Barge Arrives On. Use the drop-down menu to choose the day (or day of the simulation) that the barge or secondary storage arrives. Use the slider to set the time of arrival.
- Click on Next to go to the Start/End tab, Prev to go to the System Specs tab, or Finish to accept all the operational parameters for this skimmer.

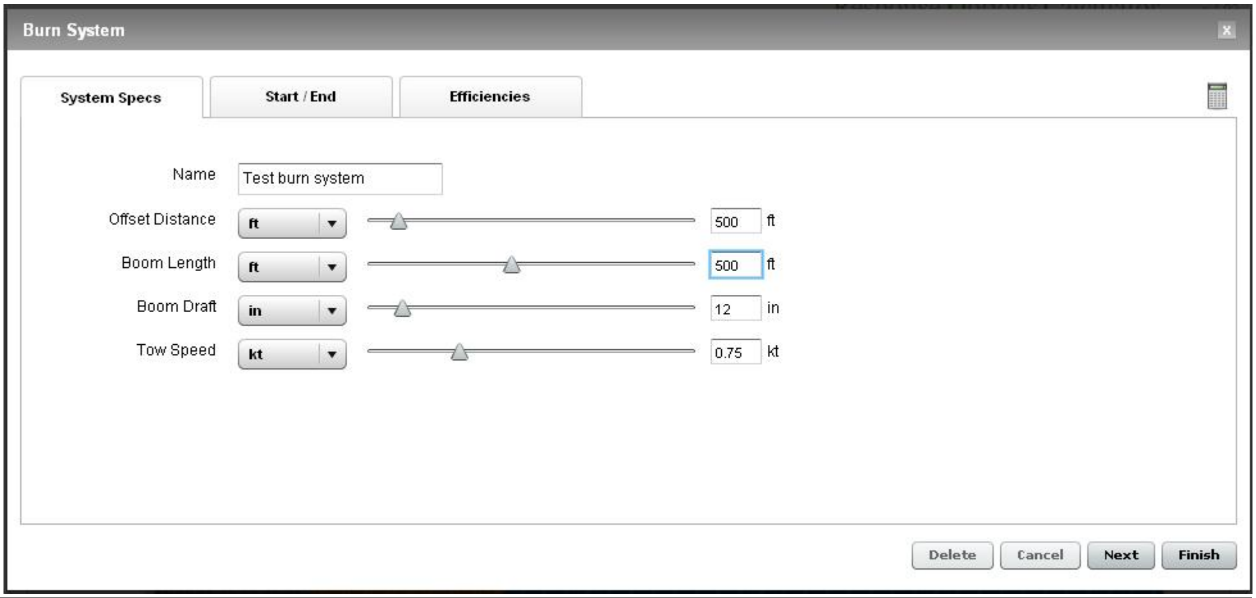



The Start/End tab is used to set the arrival date/time of the skimming system, the end of skimming for this system for the first day, and the start/end times for days until the end of the simulation. In this example, the skimming system begins at noon on day 1 of the simulation and the default times of sunrise/sunset are start/end times for days 2, 3, and 4. The start and end of the simulation are shown as red dots.



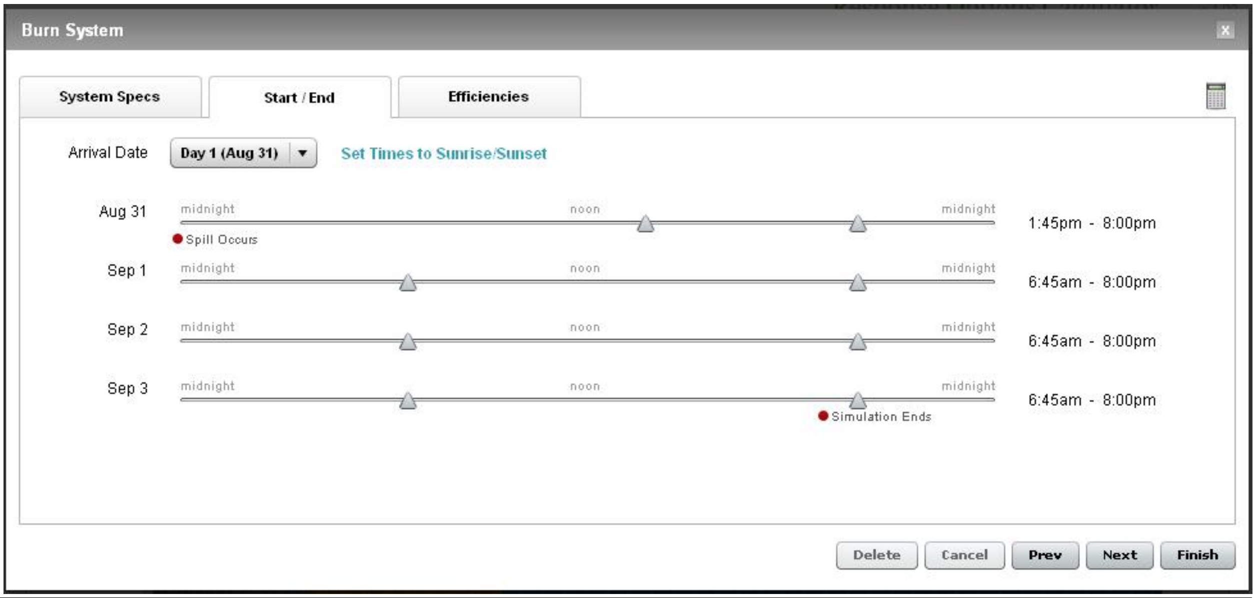

The Efficiencies tab is used to set the Skimmer Group, the Throughput Efficiency, and the Recovery Efficiency. Skimmer Groups can be seen in Figures 1 & 2 – in general, Group A (oleophillic) Recovery Efficiencies are higher than for Group B (paddle belt) which are higher than Group C (wier).

ISB Platforms

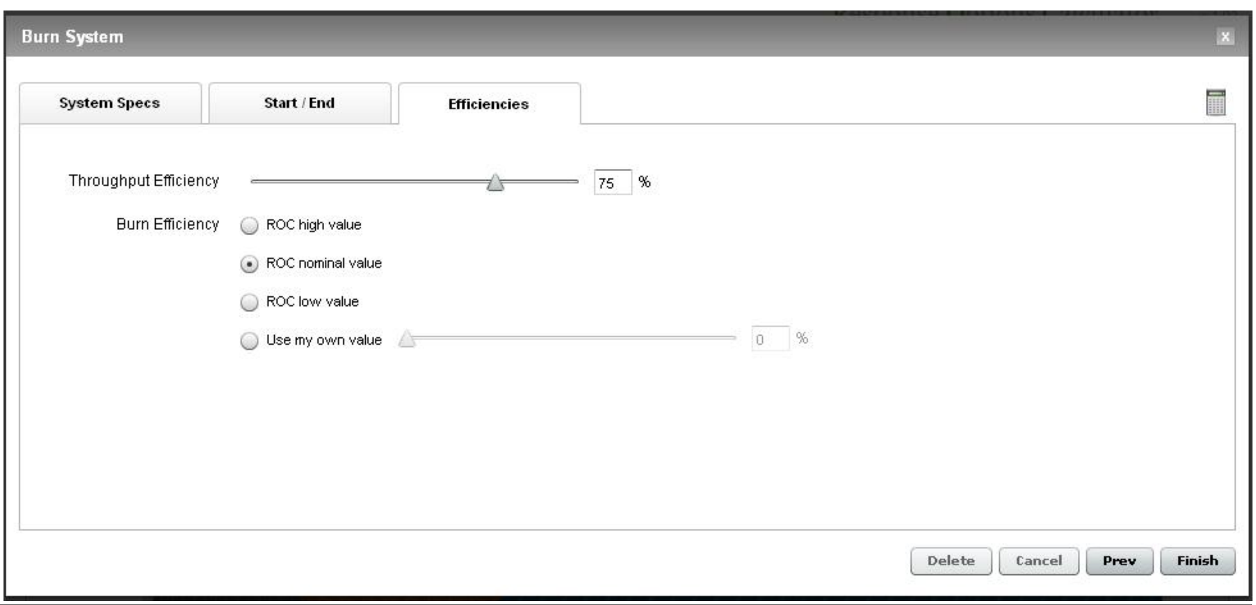



The System Specs tab contains user input to define the Burn System. Note that there are no burn systems defined in the ROC library.

- Name – Enter the unique name of the burn system.
- Offset Distance – This is an optional entry. If used, it is the distance the filled boom is towed before ignition.
- Boom Length – Fire boom is typically available in lengths of 50 feet.
- Boom Draft – The distance from the water surface to the bottom of the skirt of the boom.
- Tow Speed – Typically less than 3/4 knot to minimize loss due to entrainment.
- Click on Next to go to the Start/End tab, or Finish to accept all the operational parameters for this burn system.

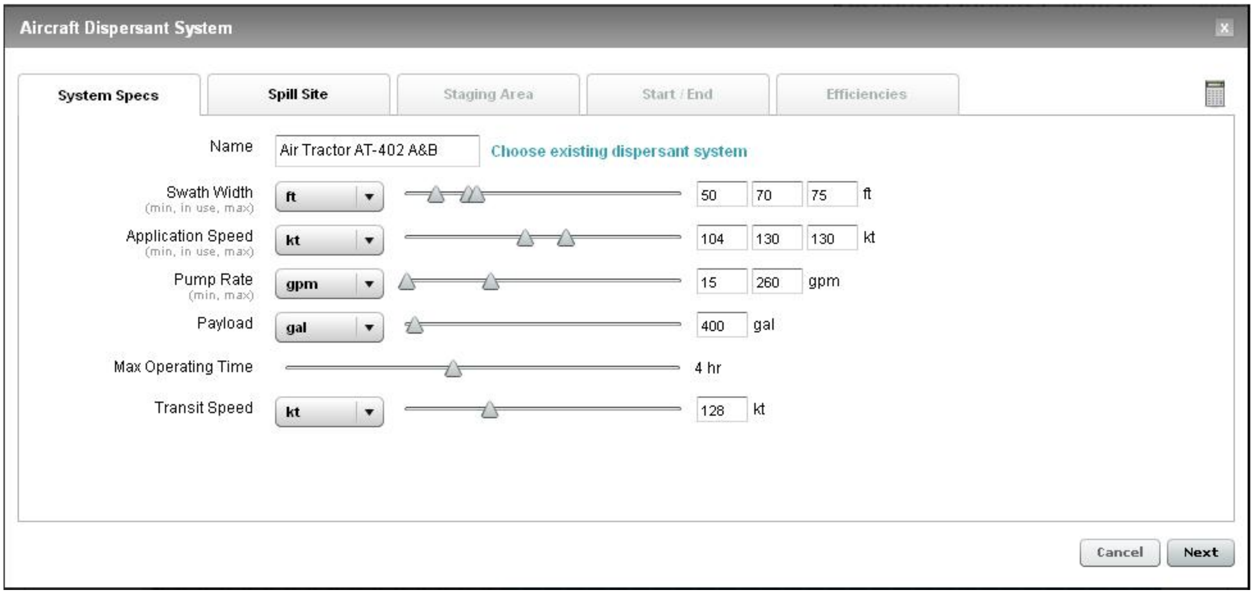



The Start/End tab is used to set the arrival date/time of the burn system, the end of oil collection for this system for the first day, and the start/end times for days until the end of the simulation. In this example, the burn system begins at 1:45 pm on day 1 of the simulation and the default times of sunrise/sunset are start/end times for days 2, 3, and 4. The start and end of the simulation are shown as red dots.

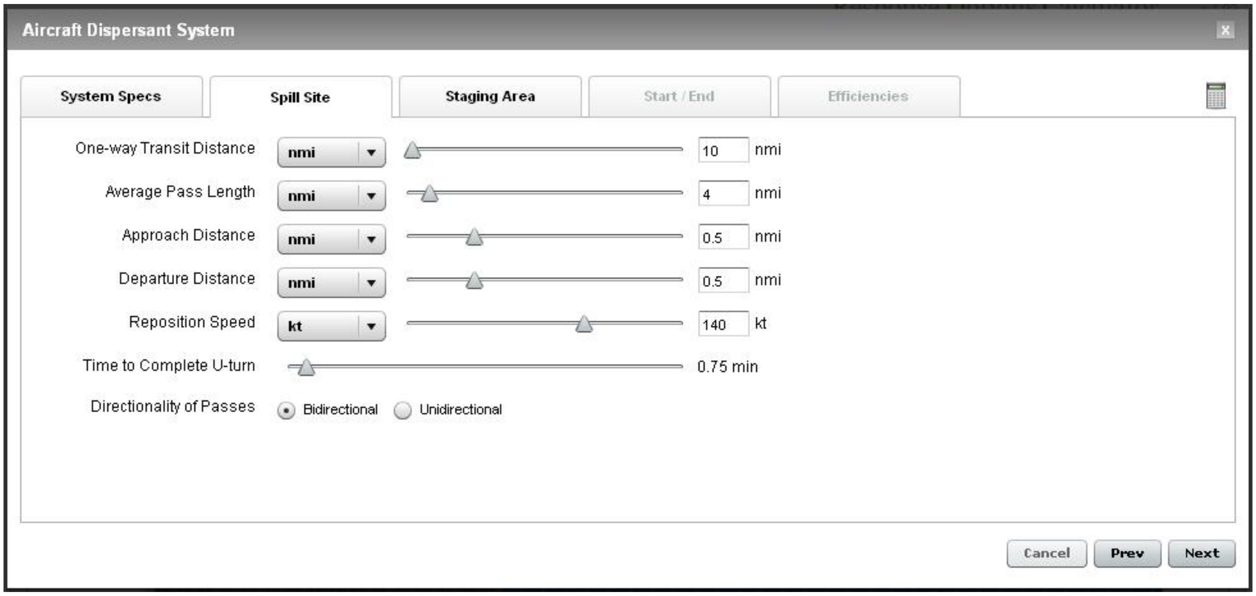



The Efficiencies tab is used to set the Throughput Efficiency, and the Recovery Efficiency. The default value of Throughput Efficiency is 75%. In this example, Burn Efficiency is set to ROC nominal value. This value will be obtained from the Burn Efficiency tables for wind/sea state and oil type.

<u>Dispersant Platforms</u>

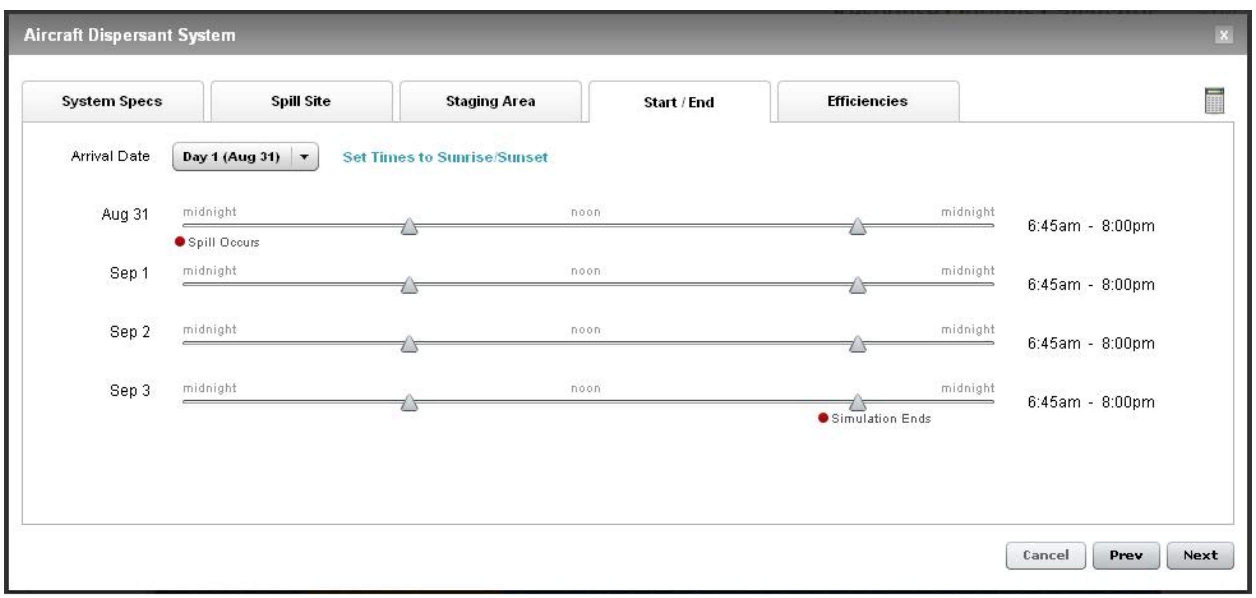



- Name - If adding a new dispersant system, enter the Name or click on "Choose existing dispersant system" to view the library of systems. When selecting an existing system, the remainder of this tab is automatically entered.
- Swath Width is the width of the dispersant spray pattern. Enter the system minimum, in use or nominal value, and maximum.
- Application Speed – Select the Speed units, then use the sliding "thumbs" to adjust to the desired values for minimum, in use, and maximum. Alternatively, click in the text boxes on the right and enter the values directly. Use the in use speed of the dispersant system while actually spraying.
- Pump Rate – enter the minimum and maximum values of dispersant pump rate values. ROC will adjust the actual pump rate to deliver the desired dosage.
- Payload is the volume of dispersant aboard.
- Max Operating Time is the time that the aerial platform can remain airborne.
- Transit Speed is the speed of the aircraft from the staging area to the spill site.
- Click on Next to go to the Spill Site tab.

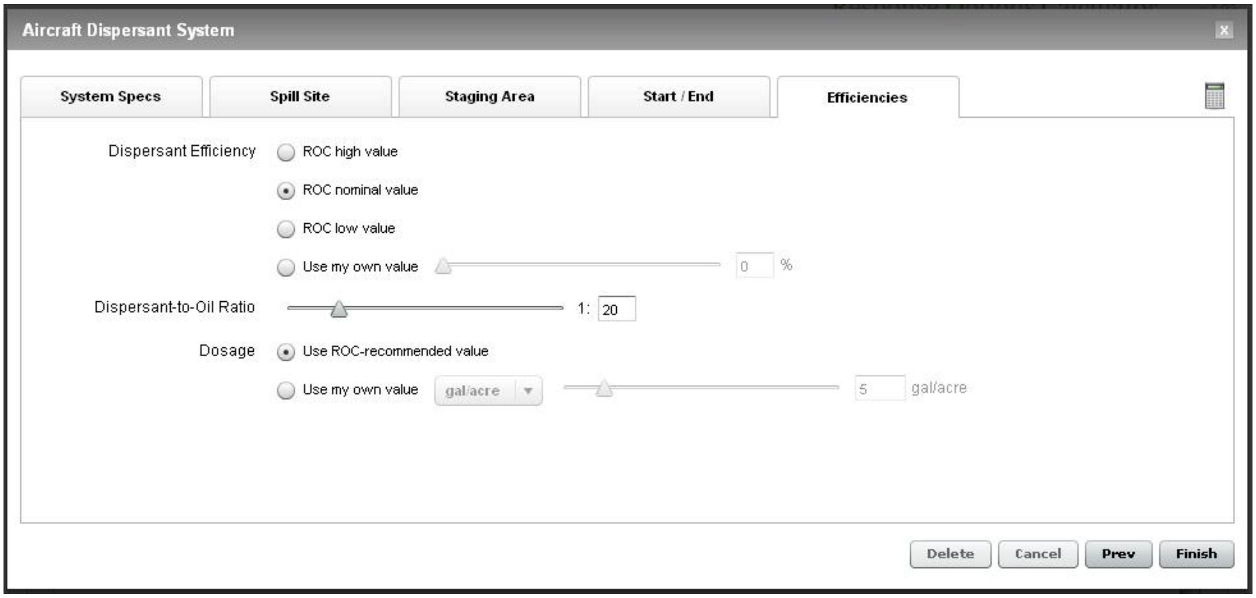



- One-way Transit Distance is the distance from the staging area to the spill site.
- Average Pass Length is the length of each spray pass over the oil spill.
- Approach Distance is that distance used by the aircraft to line up for the next spray pass, come to spray altitude and application speed.
- Departure Distance is that distance used by the aircraft to leave spray altitude, come to Reposition Speed and prepare for a U-turn.
- Reposition Speed is the speed used by the aircraft while maneuvering at the spill site.
- Time to Complete U-turn is the time used by the aircraft to make a U-turn.
- Directionality of Passes, Bidirectional or Unidirectional – Bidirectional means that the aircraft sprays in both directions (usually upwind and downwind). Unidirectional means that after a spray pass the aircraft will perform a departure and a U-turn, proceed to the other end of the Pass Length, make another U-turn, and perform an approach before the next spray pass.
- Click Next to go to the Staging Area tab, Prev to go to the System Specs tab.


- The Staging Area tab contains information about the dispersant staging area where fuel and dispersant are loaded.
- TakeoffLanding Time is the time necessary for the aircraft to takeoff and to land.
- Time to Load Fuel is the time necessary to load fuel in the aircraft.
- Time to Load Dispersant is the time necessary to load dispersant in the aircraft.
- Loading of Fuel/Dispersant – Simultaneous or Separate. If Simultaneous is selected the larger of the two times is used for reloading. If Separate is selected, the two times are additive.
- Click Next to go to the Start/End tab, Prev to go to the Spill Site tab.




The Start/End tab is used to set the arrival date/time of the dispersant system, the end of dispersant spraying for this system for the first day, and the start/end times for days until the end of the simulation. In this example, the dispersant system begins at 6:45 am on day 1 of the simulation and the default times of sunrise/sunset are start/end times for days 2, 3, and 4. The start and end of the simulation are shown as red dots.

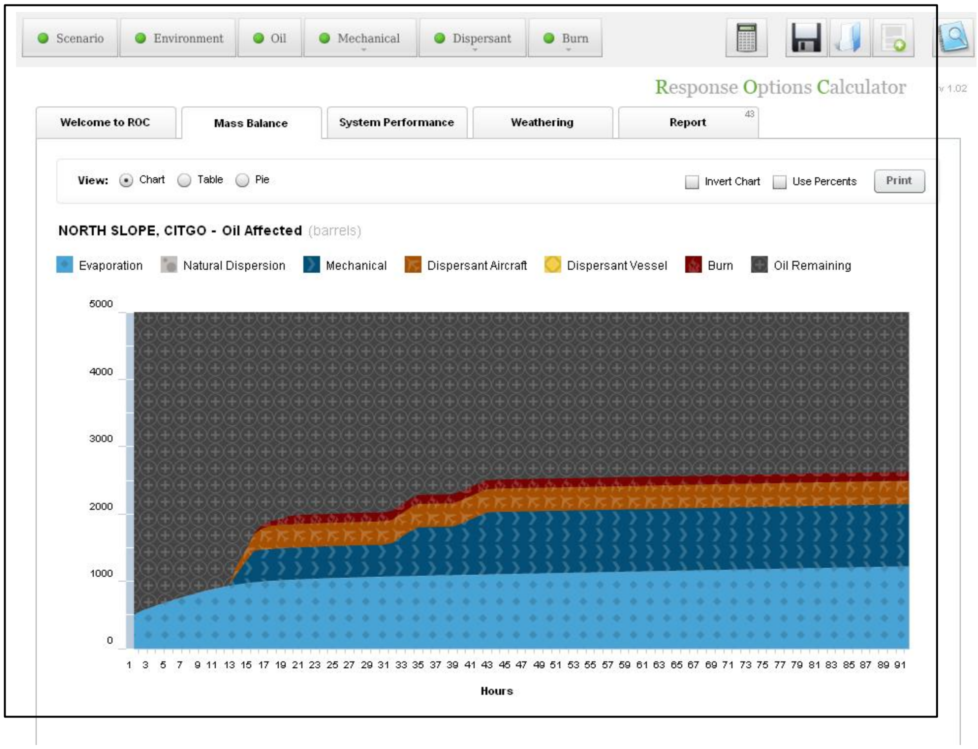



The Efficiencies tab is used to set the Dispersant Efficiency, The Dispersant-to-Oil Ratio, and the Dosage.

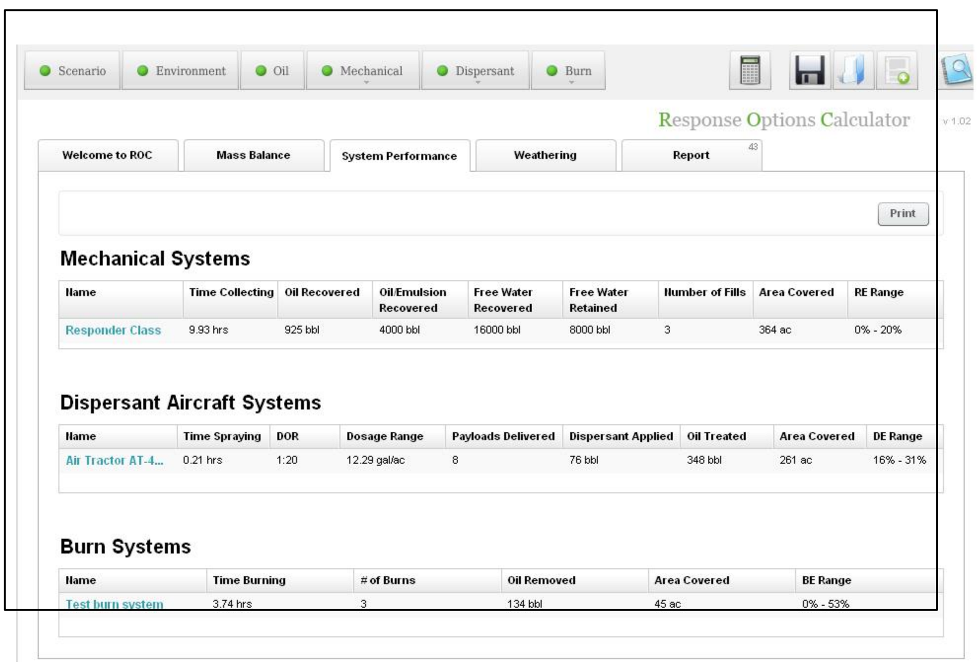
- Dispersant Efficiency – The ROC nominal value is shown on the Dispersant Efficiency Diagrams (Figures 5 & 6) as a curve through the middle of the yellow shaded area that represents an envelope of Efficiency values. Discrete values of Dispersant Efficiency are determined for a given wind/sea condition (Figure 5) and a given oil type/condition (Figure 6). ROC will use the lesser of the two values.
- Dispersant-to-Oil Ratio (DOR) – the default value is 1:20 which indicates one volume of dispersant will treat 20 volumes of oil. This value can be changed via the slide bar or by direct entry into the field on the right.
- Dosage – User ROC-recommended value or Use my own value. ROC can determine a Dosage value based on the DOR and the thickness of the oil slick. Because the thickness varies with time, this Dosage will also vary with time within the simulation. User entered Dosages will remain constant for the duration of the simulation.

ROC Output

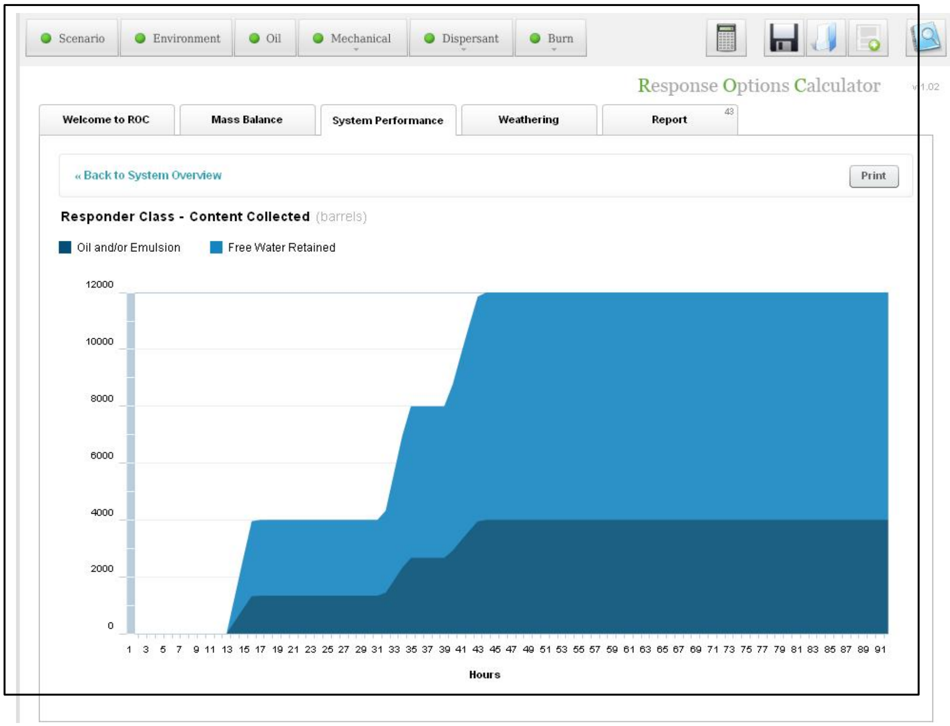
The following diagram is an example of Mass Balance for a ROC simulation.



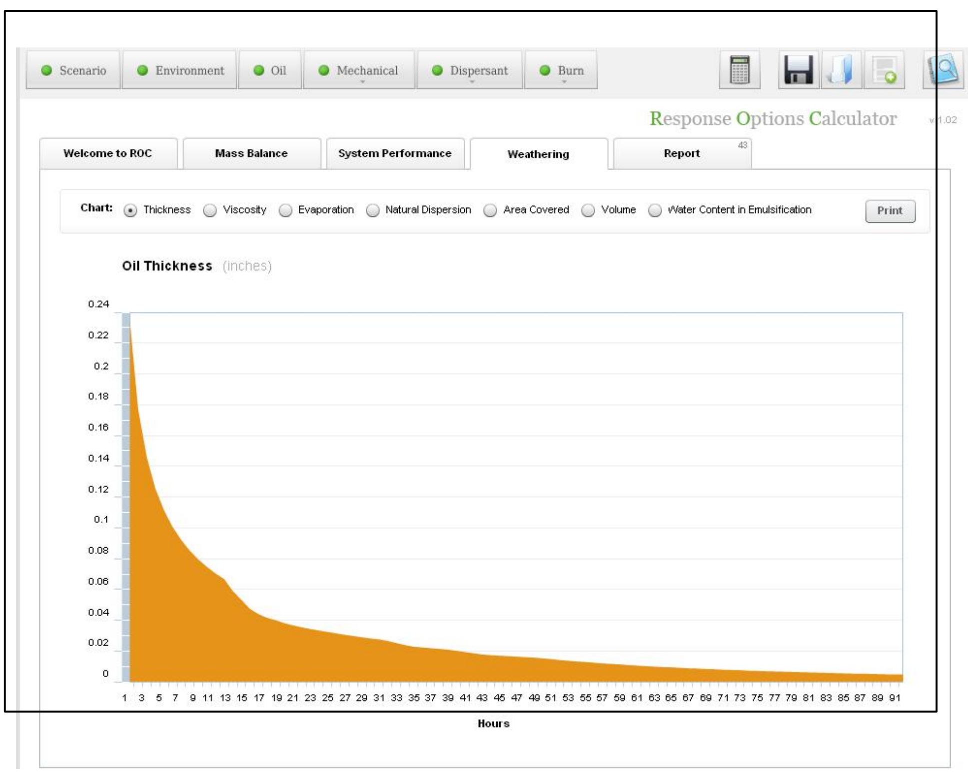

The following diagram is an example of the System Performance tab showing a summary of all response systems assigned to a simulation.

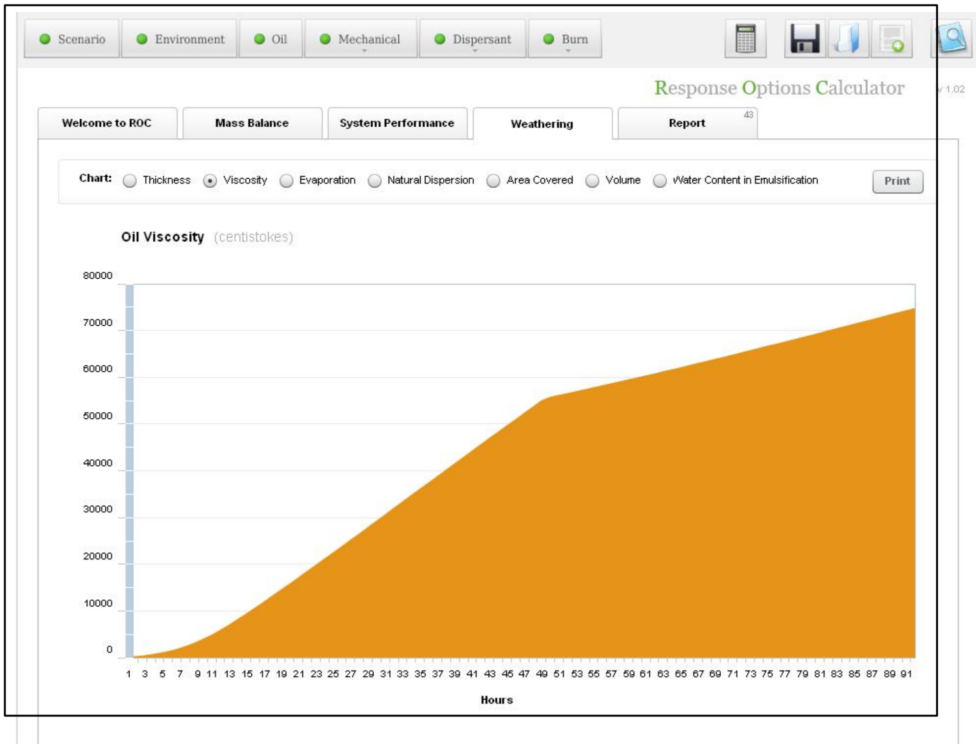



The following diagram shows individual performance of a response countermeasure, in this case a skimmer. The amounts of oil/emulsion and free water recovered are shown graphically. Note that the previous diagram also shows an estimate of the total oil (not oil/emulsion) recovered during the simulation.

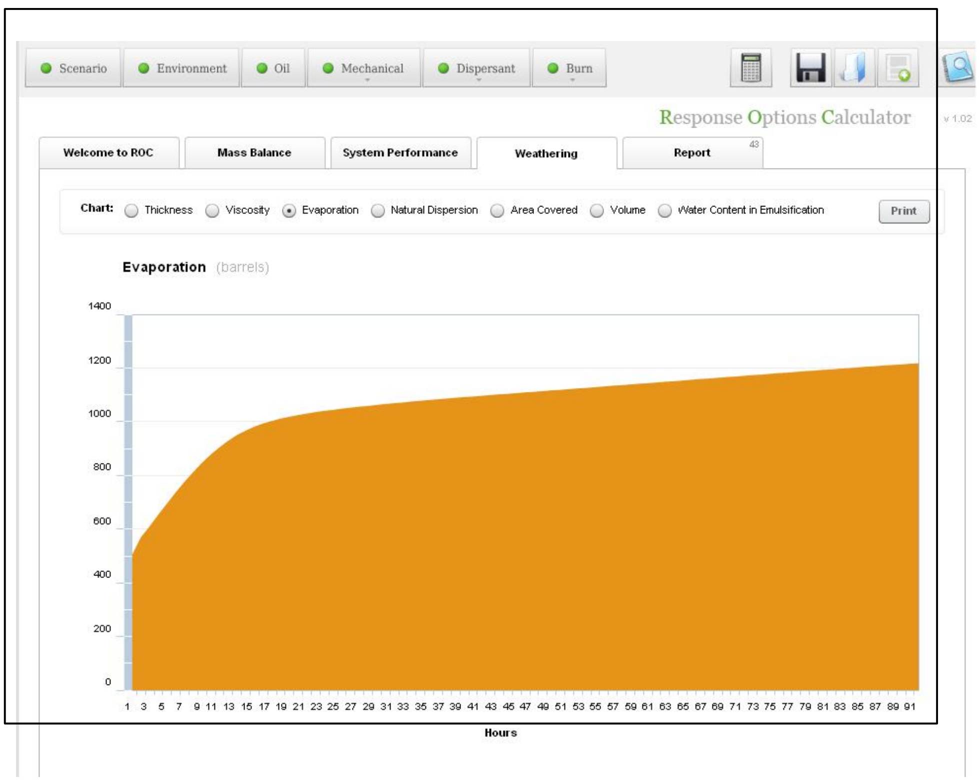



The following diagrams show the options available in the Weathering tab. The first is the modeled oil Thickness during the simulation. Turning off and on the assigned response countermeasures cause an immediate effect on Thickness and Volume.

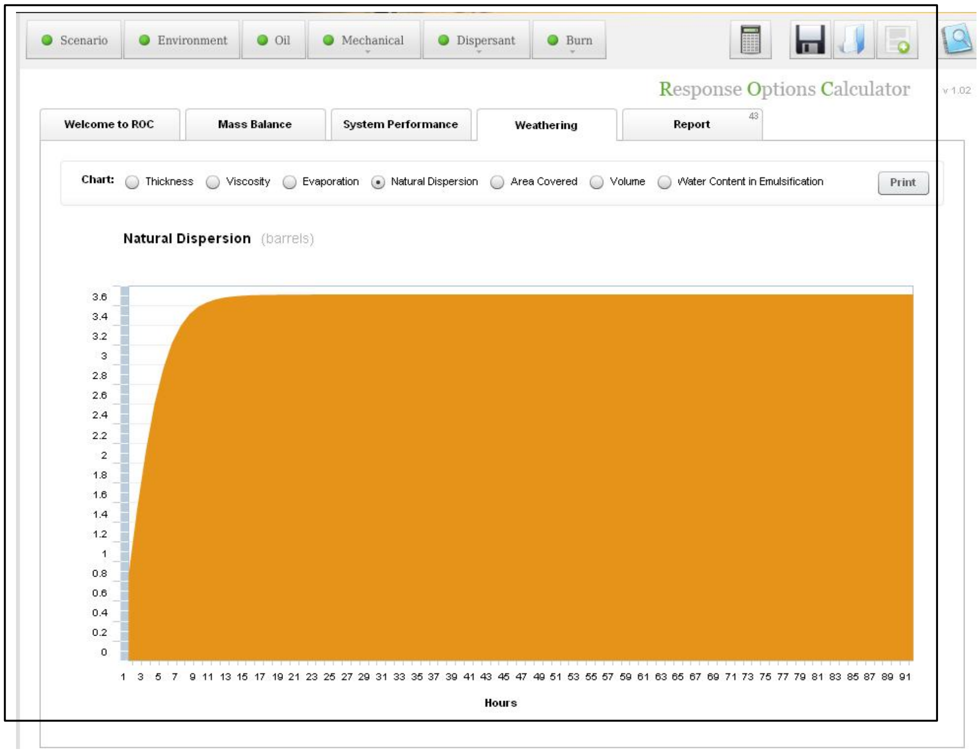




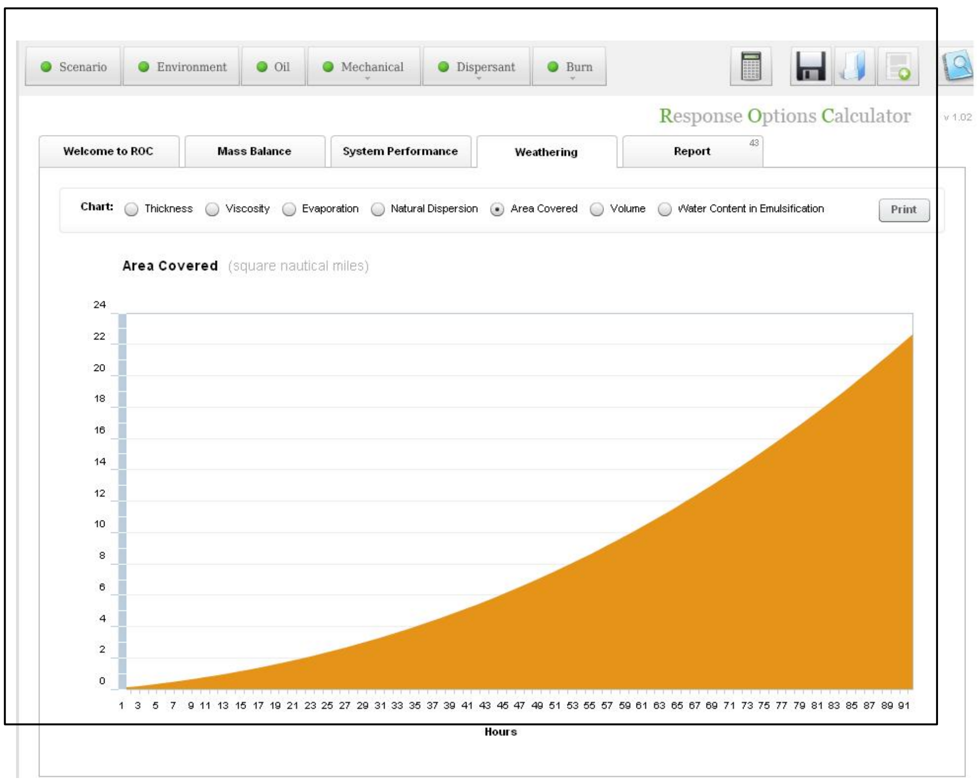

Oil Viscosity



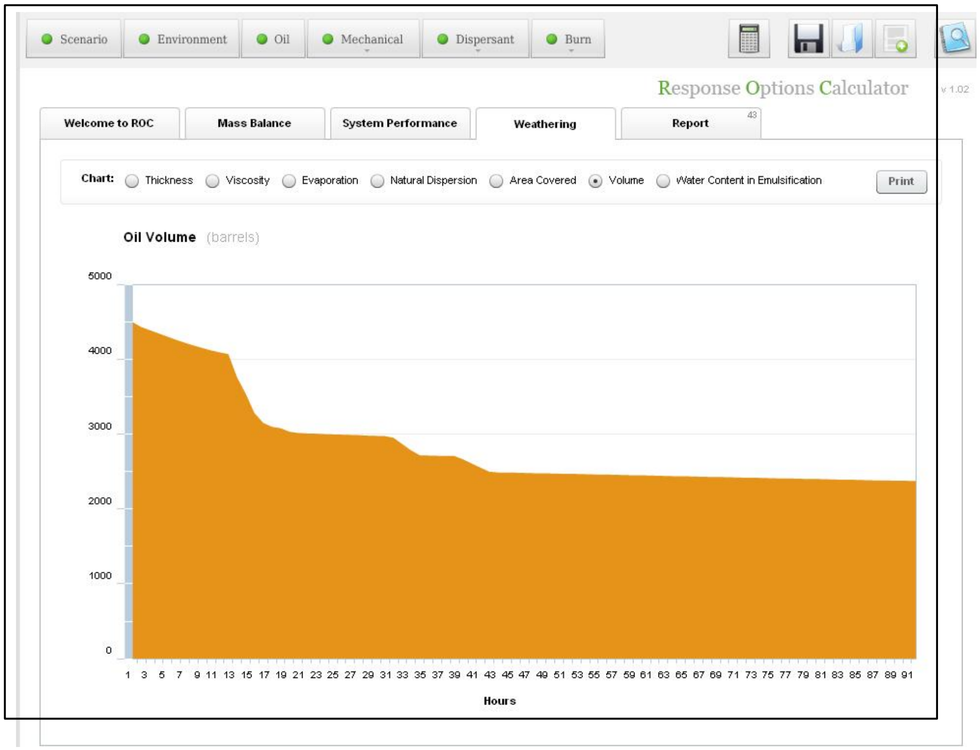

Evaporation



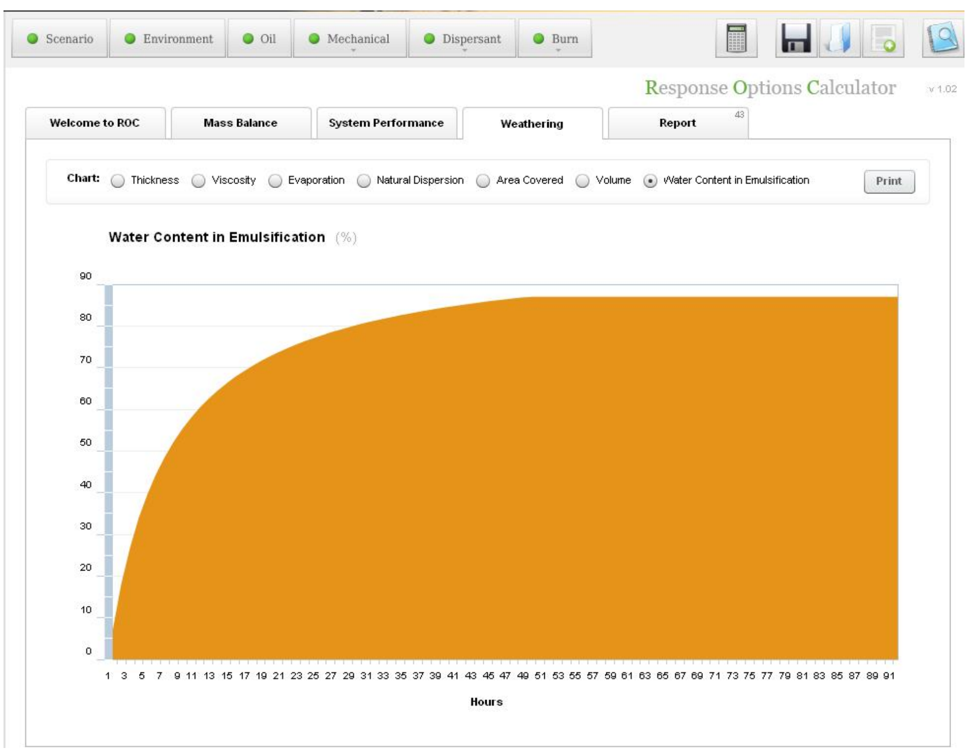

Natural Dispersion




Area Covered

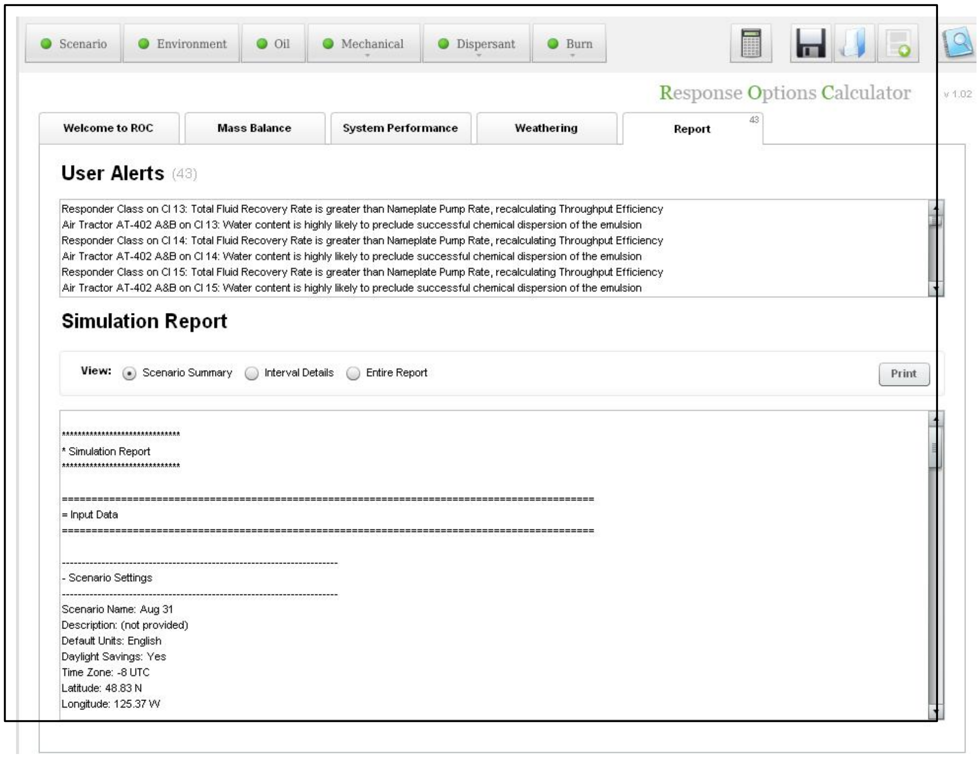



Volume




Water Content in Emulsion

The following graphic illustrates the Report tab. User Alerts, if any, appear at the top. The user can choose various levels of detail in the Simulation Report – Scenario Summary, Interval Details, or the Entire Report.




Bibliography

[1]Galt, J.A., and Roy Overstreet, "Development of Spreading Algorithms for MARO (Model for Assessment of Response Options). Genwest Systems, Inc. Technical Note, May 2009.

Allen, A.A. "Comparison Of Response Options For Offshore Oil Spills", Proceedings, 11th AMOP Technical Seminar, Vancouver, B.C., Canada, June, 1988.

[2] Allen, A.A., Dean H. Dale, and Chris Gregory,"Assessment of Potential Oil Spill Recovery Capabilities", Proceedings, 1999 International Oil Spill Conference, Seattle, Washington, March 8-11, 1999.

Allen, A.A., and Dean Dale "Dispersant Mission Planner: A Computerized Model For The Application of Chemical Dispersants On Oil Spills", Proceedings, 18th Annual AMOP Technical Seminar, Edmonton, Alberta, Canada, June, 1995.

[3] "Vessel and Facility Response Plans for Oil: 2003 Removal Equipment Requirements and Alternative Technology Revisions", CFR Parts 154 and 155, Federal Register/Vol. 74, No. 167/Monday, August 31, 2009/Rules and Regulations.

[4] Lewis, Alun, "Current Status of the BAOAC (Bonn Agreement Oil Appearance Code)", A Report to the Netherlands North Sea Agency Directie Noordzee, January 2007.

ASTM F2534-06 Standard Guide for Visually Estimating Oil Spill Thickness on Water.

ASTM F631-93 Standard Guide for Collecting Skimmer Performance Data in Controlled Environments.

ASTM F1413-07 Standard Guide for Oil Spill Dispersant Application Equipment: Boom and Nozzle Systems.

ASTM F2532-06 Standard Guide for Determining Net Environmental Benefit of Dispersant Use.

ASTM F1788-97 (2003) Standard Guide for In-Situ Burning of Oil Spills on Water: Environmental and Operational Considerations.