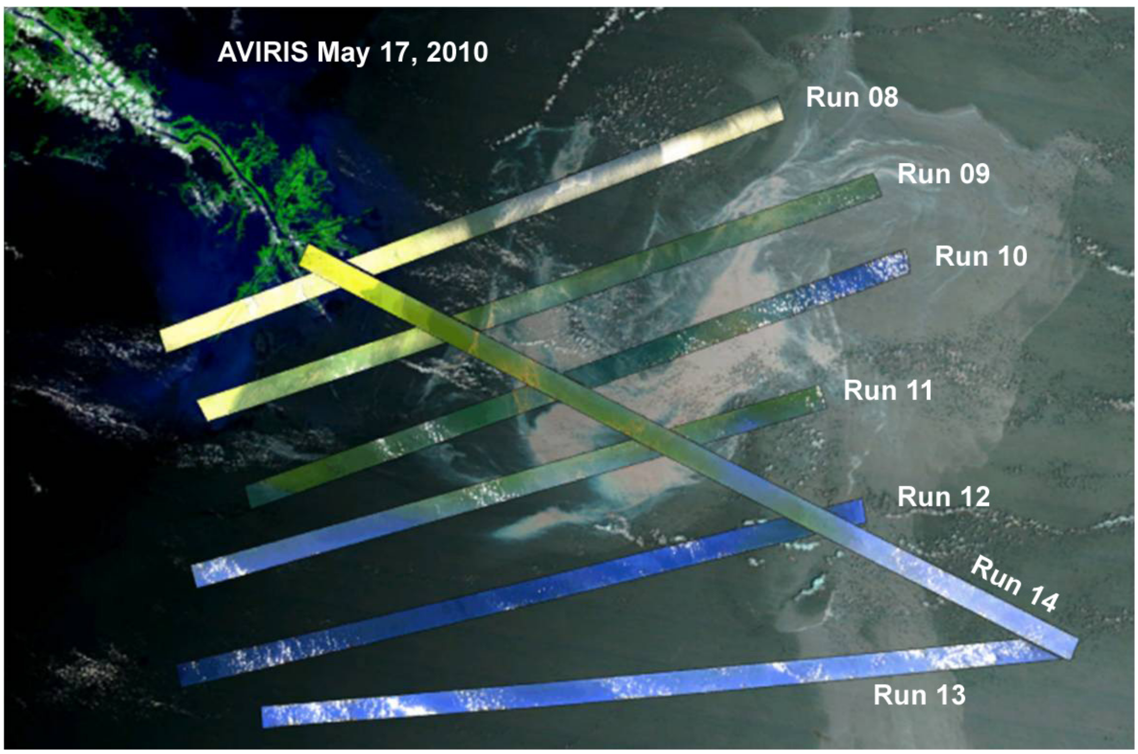
Estimated Minimum Discharge Rates of the Deepwater Horizon Spill—Interim Report to the Flow Rate Technical Group from the Mass Balance Team

By Victor F. Labson, Roger N. Clark, Gregg A. Swayze, Todd M. Hoefen, Raymond Kokaly, K. Eric Livo, Michael H. Powers, Geoffrey S. Plumlee, and Gregory P. Meeker



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Conversion Factors

Inch/Pound/Gallon/Barrel to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha), which is 10,000 m^2
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2), a section or 640 acres	259.0	hectare (ha) [1 ha = 10,000 m^2]
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallons (gal)	3.7854	liters (l)
barrels (bbl)	158.99	liters (l)

SI to Inch/Pound/Gallon/Barrel

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Area		
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2), a section or 640 acres
square kilometer (km^2)	0.3861	square mile (mi^2)
Volume		
liters (l)	0.26417	gallons (gal)
liters (l)	0.00629	barrels (bbl)

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Purpose

All of the calculations and results in this report are preliminary and intended for the purpose, and only for the purpose, of aiding the incident team in assessing the extent of the spilled oil for ongoing response efforts. Other applications of this report are not authorized and are not considered valid. Because of time constraints and limitations of data available to the experts, many of their estimates are approximate, are subject to revision, and certainly should not be used as the Federal Government's final values for assessing volume of the spill or its impact to the environment or to coastal communities. Each expert that contributed to this report reserves the right to alter his conclusions based upon further analysis or additional information.

Summary

An estimated minimum total oil discharge was determined by calculations of oil volumes measured as of May 17, 2010. This included oil on the ocean surface measured with satellite and airborne images and with spectroscopic data (129,000 barrels to 246,000 barrels using less and more aggressive assumptions, respectively), oil skimmed off the surface (23,500 barrels from U.S. Coast Guard [USCG] estimates), oil burned off the surface (11,500 barrels from USCG estimates), dispersed subsea oil (67,000 to 114,000 barrels), and oil evaporated or dissolved (109,000 to 185,000 barrels). Sedimentation (oil captured from Mississippi River silt and deposited on the ocean bottom), biodegradation, and other processes may indicate significant oil volumes beyond our analyses, as will any subsurface volumes such as suspended tar balls or other emulsions that are not included in our estimates. The lower bounds of total measured volumes are estimated to be within the range of 340,000 to 580,000 barrels as of May 17, 2010, for an estimated average minimum discharge rate of 12,500 to 21,500 barrels per day for 27 days from April 20 to May 17, 2010.

Description of Approach

The Mass Balance Team approach combined remote-sensing-based estimates of oil volumes at the sea surface with estimates provided to the group by NOAA (National Oceanic and Atmospheric Administration), NASA (National Aeronautics and Space Administration), and USCG on volume of oil skimmed, volume of oil burned, and percentage of oil evaporated or dissolved in seawater.

The remote sensing estimates of oil volumes at the ocean surface were determined from analysis of data obtained from space and airborne sensor measurements of the surface oil in the Gulf of Mexico on May 17, 2010. A multichannel MODIS (MODerate-resolution Imaging Spectroradiometer) satellite image (250×250 meter pixels) from that day was used to estimate the total surface area of oil on the water (about 17,725 km2). The determination was based on higher surface signal return to the sensor from areas with oil sheens, slicks, and floating plumes of oil/water emulsion than from average baseline clean ocean areas.

The percentages of total ocean surface oil coverage considered to be “thick” (2 percent), “dull” (10 percent), or “sheen” (88 percent) were provided by NOAA and the USCG. Applying these percentages to the total estimated ocean surface oil coverage area on May 17, 2010, resulted in 350 km2 of “thick,” 1,775 km2 of “dull,” and 15,600 km2 of “sheen.”

Thick Oil (2 Percent of Surface Oil Coverage Area)

Aircraft-based AVIRIS (Airborne Visible/Infra-Red Imaging Spectrometer, 224 channels, 8.5×8.5 meter pixels) imaging spectroscopy data were also collected over 967 km2 of the oil coverage area on May 17 and were used to map and characterize thicker emulsion-bearing regions. The higher resolution of the AVIRIS data allows a more refined estimate than MODIS of the thicker oil emulsions that commonly occur in wispy or ropy patterns on the sea surface, separated by substantial areas of much thinner oil accumulations. Laboratory reflectance measurements of oil/water emulsion samples (“thick” oil) collected on a traverse of the spill on May 7 were used to develop an algorithm for conversion of AVIRIS response to oil volume per pixel. These values were extrapolated from the 967 km2 AVIRIS coverage to the full estimated 3,363 km2 of MODIS-derived emulsion-bearing regions. This procedure, described in a report in preparation (R.N. Clark and others, written commun., 2010), provided an estimated range of 66,000 to120,000 barrels of oil in the emulsion-bearing regions. The total area recognized by the AVIRIS algorithm as “thick” oil, when compensated for the total emulsion-bearing region covered by AVIRIS, results in a measurement of 1.83 percent of the total surface oil coverage area showing “thick” oil. This is independent of the percentage assignments provided by NOAA and USCG, and allows a confident assignment of this AVIRIS minimum estimate to the expected 2 percent surface area of “thick” oil.

The two numbers (66,000 and 120,000) represent a range of the minimum volume of oil determined from less and more aggressive assumptions built into the AVIRIS estimation algorithm for detecting surface oil between 25 micrometers (µm) and 20 millimeters (mm) in thickness. The thickness of oil that can be detected with infrared spectroscopy (AVIRIS) varies with the oil-to-water ratio (R.N. Clark and others, written commun., 2010). As the oil fraction increases, the oil layer becomes dark, limiting the light energy penetration depth. The AVIRIS algorithm varies oil volume on the basis of pixel value response according to oil thickness and oil:water ratios for determined thicknesses up to 4 mm. Only the more aggressive calculation includes oil volumes for regions with thicknesses greater than 4 mm, and only with an assumption of 20 mm thickness when the oil-to-water ratio is less than or close to 2 percent. The volume of oil below the upper 4 mm of more oil-rich emulsions (where oil-to-water ratio is greater than 2 percent) was not evaluated with AVIRIS and could substantially increase the oil volume values reported herein. As noted below, estimated “dull” oil volumes are due to surface oil thickness in the range of 3 to 6 microns. Surface oil volumes due to oil thicknesses greater than 6 µm and less than 25 µm, or thicknesses greater than 20 mm, could also be significant and are not included at all in this estimate.

Dull (10 Percent Surface-Oil Coverage Area) and Sheen Oil (88 Percent Surface-Oil Coverage Area)

The amount of oil in the 1,775 km2 of “dull” area and the 15,600 km2 of “sheen” area was estimated assuming a range of oil thickness for each area that falls within color-based thickness ranges assigned by an ASTM standard method (American Society for Testing and Materials, 2006) for visually estimating oil spill thickness on water. For the “dull” area the assumed thickness range was 3 to 6 µm, and for the “sheen” area the assumed thickness range was 0.3 to 0.6 µm. This resulted in estimated oil volume ranges for the spill of 33,500 to 67,000 barrels in thin “dull” areas and 29,500 to 59,000 barrels in thin “sheen” areas. Summing the “thick,” “dull,” and “sheen” volumes gives a minimum surface oil estimate over the MODIS-determined area of the spill on May 17, 2010, of 129,000 to 246,000 barrels of oil.

Oil Skimmed, Burned, Evaporated, Dissolved, and Dispersed

Additional estimates of oil volumes were provided to the group and included 23,500 total barrels of oil skimmed as of May 17 (USCG data), 11,500 total barrels of oil burned as of May 17 (USCG data), and 40 percent of surface oil evaporated or dissolved (NOAA data). To determine the amount of oil prior to evaporation or dissolution in seawater, the amounts skimmed and burned are added to the range of amounts estimated present on the surface on May 17. The sum is considered to be about 60 percent of the total oil volume reaching the surface, which is calculated by dividing the observed, skimmed, and burned sum by 0.6. The difference between the total and observed amounts yields a range of evaporation and dissolution volume from 109,000 to 185,000 barrels.

Subsea dispersants were applied for a total effective time of 5.3 days over the 27 days from the start of the leak and May 17 (Jeffrey Hohle, BP, written commun., 2010). We therefore do not include subsea-dispersed volume in our surface oil sum, and have accounted for this by dividing our volume totals by 21.7 days rather than 27 days. We further assume that, due to the lack of significant wave action over the period when dispersants were applied on the surface (USCG data), the remote-sensing measurements include surface oil treated with dispersants.

Estimated Discharge Rates Based on Observed and Calculated Volumes

We estimate that a minimum of 273,000 to 466,000 barrels of oil discharged over 21.7 days. This results in a minimum estimated average oil discharge rate per day of 12,500 to 21,500 barrels. The values in barrels are summarized in the following table.

Low minimum	High minimum	Explanation
66,000	120,000	2 percent area “thick” oil from imagery
33,500	67,000	10 percent area “dull” oil
29,500	59,000	88 percent area “sheen” oil
129,000	246,000	Total observed on surface
23,500	23,500	skimmed oil
11,500	11,500	burned oil
164,000	281,000	Subtotal as of May 17, 2010
109,000	185,000	40 percent evaporation and dissolution
273,000	466,000	Total estimated as of May 17, 2010
12,500	**21,500**	**Daily average per 21.7 days**
67,000	114,000	assumed subsea dispersion
340,000	580,000	estimated leaked as of May 17

This summary includes the best available information as of this writing and is a refinement of previous estimates. We are continuing to refine these estimates by gathering further information that will help reduce potential sources of uncertainty in several parts of the mass balance calculations.

References Cited

American Society for Testing and Materials, 2006, Standard guide for visually estimating oil spill thickness on water: ASTM International F2534 – 06, 4 p. Accessed May, 2010 from *http://www.astm.org/Standards/F2534.htm*