The estimation of regional oil recovery capacity based on marine oil spill response scenario in Vietnam

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ABSTRACT
The oil spill recovery capacity-OSRC plays a vital role in setting up national or regional response capability to combat the big risk of marine oil spills from oil transportation activities around Vietnam. However, in preparedness for marine oil spills, it is not known how much the amount of OSRC Vietnam should have. In this study, the criteria of marine developed countries for the establishment of marine OSRC are reviewed, and Vietnamese current conditions based on oil transportation and offshore activities are examined. In addition, Vietnamese marine oil spill recovery scenario is created, and therefrom Vietnamese regional oil spill recovery demand-OSRD and regional OSRC are estimated quantitatively through the calculations with the main factors such as the maximum amount of oil spill, the percentage of oil quantity remaining on water, emulsification factor, mobilization factor, total nominal throughput rate of all oil recovery devices. This contribution is necessary to improve and reinforce the areal, regional, and national OSRCs or aOSRCs in conformity with the corresponding areal, regional, and national OSRDs or aOSRDs in Vietnam and to balance properly the allocations of OSRCs or aOSRCs by area, by region, and nationwide in Vietnam, on the basis of the scientific and quantitative estimation results.

Introduction
Marine oil pollution control policy needs to identify the major sources of oil pollution in the sea area, which may be assumed to be oil spill incidents along oil transport sea routes. The worst case discharge (WCD) from oil tanker can be estimated through the calculation of maximum amount of oil spill by hypothetical oil outflow according to MARPOL 73/78 (IMO 2003, 2004; Phan 2017), thereby National Contingency Plan or Regional Contingency Plan (RCP) can be made to ensure equipment, personnel, and additional support for each area in a country. Actually, the advanced countries such as United States of America (USA), Canada, Japan, and South Korea have assumed the largest oil spill by region from the target vessel for the estimation of regional marine OSRC (oil spill recovery capacity) (USCG 2008a, 2008b; CCG 2011; JCG 2017; KOEM 2011). From there, the forces and facilities are built to ensure proper management and flexible mobilization of OSR (oil spill response) resources between regions within their country.

Vietnam mentioned the possibility of response to oil spillages at various levels, such as grassroots, regional, and national levels, in legal documents such as Decision No. 02 (VPM 2013) and Official letter No. 69 (VINASARCOM 2009). In a case where the level of oil spill is high or complicated and beyond the capability of the relevant units, the forces and equipment shall be requested to the superior agencies and the specialized units in the localities to be dispatched to spill site for support. However, there is no specific document or research specifying the criteria for calculating and building OSRCs such as target vessels, maximum oil spills from ships, the percentage of oil response at sea, duration of response process as well as a model for calculating response performance capacity of equipment such as oil skimmer, oil boom, and oil temporary storage in Vietnam.

Therefore, in this study, the criteria of marine developed countries for the establishment of national or regional OSRC were reviewed and the Vietnamese current conditions were examined based on oil transportation and offshore activities in Vietnam. Therefrom, Vietnamese regional OSRD (oil spill recovery demand) and nominal mechanical OSRC were estimated on the basis of marine OSR scenario through the calculation with major factors such as the maximum amount of oil spill, oil quantity remaining on water, emulsification factor, mobilization factor, total nominal throughput rate of all oil recovery devices, the number of operating day, and working time per day. Finally, the estimated OSRD (or actual OSRD [aOSRD]) and OSRC (or actual OSRC [aOSRC]) were compared each other to propose the alternative plans for the improvement and reinforcement of Vietnamese marine OSRC.

The results of this study are expected to contribute to the advancement of marine OSR capability in Vietnam.
Concepts of OSRD and OSRC

Regional OSRD and OSRC

OSR capability is defined as the resources to deal with the oil spill incident, including three categories: equipment, personnel, and supplementary support (IPIECA-IOGP 2015). Therefore, OSR capability may include response personnel, additional response support, and many possible response options such as mechanical method (or containment and recovery of the oil at sea by booms, skimmers, and sorbents), chemical dispersion of oil at sea by dispersants, in situ burning, natural disintegration, and bioremediation.

OSR demand ($t$ or $m^3$) means the maximum amount of oil remaining on the sea surface, which demands to be responded to and to be removed fully from the sea surface or be cleaned up completely using all the possible response options in order to minimize the damage to properties or coastal resources and to protect the marine environment.

OSRD ($t$ or $m^3$) means the maximum amount of oil remaining on the sea surface after natural dissipation processes such as evaporation of the spilled oil for a specified period of time, which demands to be recovered fully or completely from the sea surface, on the assumption that oil spill remains on and is distributed over the sea surface in the defined sea area or region like the ideal batch system, using all the recovery devices such as oil skimmer in order to minimize the damage to properties or coastal resources and to protect the marine environment. OSRD may be a part of OSR demand, but both are different from each other. There may be national OSRD, regional OSRD, areal OSRD, or facility OSRD.

Regional OSRD ($t$ or $m^3$) means the maximum amount of spilled oil, which demands to be recovered fully or completely from the sea surface of the defined region after natural dissipation processes of spilled oil for the specified operating days, considering the type of oil spill stated in RCP.

Regional aOSRD ($t$ or $m^3$) refers to regional OSRD in the defined region for the specified period (i.e., for 4 days) considering the maximum amount of marine oil spill, the percentage of oil remaining on the sea surface, emulsification factor, and mobilization factor through the entire response activity chains to recover the oil from the sea surface of the spill site.

OSRC ($t$ or $m^3$) set by the advanced marine countries means the maximum capacity for the recovery of spilled oil, or total amount of the spilled oil which can be recovered from the sea surface by oil recovery devices or systems such as oil booms, oil skimmers, temporary oil storage tanks, oil recovery vessels and sorbents. OSRC may be expressed in any unit such as weight ($t$) or volume ($m^3$) for the specific period (i.e., for 3 days). There may be national OSRC, regional OSRC, area OSRC, or facility OSRC. In this study, OSRC is supposed to be calculated only by total nominal throughput rate of all oil recovery devices such as oil skimmers, without consideration of oil boom, oil temporary storage, sorbent, etc.

Nominal oil spill recovery rate or nominal throughput rate ($t/h$) means the hourly throughput rate of an oil recovery device or oil skimmer, which is displayed on the plate of the device or the skimmer by manufacturer.

Regional nominal daily OSRC ($t$/day) refers to total throughput rate of all oil recovery devices in the defined region for a day (or total daily recovery capacity of all skimmers in a region).

Regional OSRC ($t$ or $m^3$) means the maximum capacity for the recovery of spilled oil from the sea surface of the defined region for the specified operating days, considering the type of oil spill stated in RCP.

Regional aOSRC ($t$ or $m^3$) or regional mechanical OSRC ($t$ or $m^3$) for the specified period refers to total throughput rate of all oil recovery devices or total oil recovery capacity of skimmers in the defined region for the specified period (i.e., for 4 days) considering the number of operating day, working time per day, efficiency factor, and mobilization factor through the entire response activity chains to recover the oil from the sea surface of the spill site.

On the other hand, the maximum oil discharge is based on hypothetical oil outflow of the largest oil tankers operating in arrival and departure areas (IMO 2003, 2004).

Situation of Vietnam

The government of Vietnam has built three national OSR centers. A total of 24 out of 28 coastal provinces have built their respective OSR contingency plans at provincial level, and various OSR contingency plans at in-house level were approved by the authorities of Vietnam. There are some solutions that have been proposed to improve OSR capability such as response measures for oil spills in Da Nang City (Phung 2005) and the enhancement of local capacities in oil spill preparedness and response (Nguyen 2009; Nguyen and Nguyen 2014). However, Vietnam still lacks scientific criteria related to marine OSRD and OSRC. The scientific and systematic researches on the criteria of OSRD and OSRC estimation are necessary in Vietnam.

Major sources of marine oil spill

In the advanced maritime countries, the biggest source of marine oil spill is assumed to be the largest vessel or oil tanker operating in their territorial sea. The major oil transport routes in Vietnam’s sea areas and the largest tankers which arrive at and depart from the ports of Vietnam are considered for the selection of target vessel in relation to regional OSRD and OSRC.
Vietnam has been carrying out effective exploration and production of offshore oil and gas, being about 420,000 barrels of oil production per day. Vietnam’s potential for gas and oil production is located in seven basins: Cuu Long basin, Con Son basin, Song Hong basin, Malay-Tho Chu basin, Phu Khanh basin, Hoang Sa basin, and Truong Sa basin group. There are seven types of crude oil which are produced from different oil fields such as Bach Ho, Dai Hung, Rang Dong, Bungakekwa/Cai Nuoc, and Su Tu Den.

The oil transport routes in Figure 1 and the major oil tankers operating in Vietnamese waters in Table 1 have shown that the risk of oil spills from oil tankers of 300,000 DWT exists in all three regions of the north, central, and south. Oil tankers of about 150,000 DWT carry crude oil from oil and gas exploration offshore in Vung Tau area to petrochemical refineries such as Dung Quat oil refinery with high operating frequency. In addition, the East Sea is one of the world’s busiest international sea-lanes. More than half of the world’s oil tankers pass through the East Sea every year.

Over half of the world’s merchant fleets sail through the East Sea every year. More than half of the world’s annual merchant fleet tonnage passes through the Straits of Malacca, Sunda, and Lombok, with the majority continuing on to the East Sea. Almost one-third of global crude oil and over half of global LNG trade pass through the East Sea, making it one of the most important trade routes in the world.

Thus, in order to estimate OSRD, the biggest source of oil spill is assumed to be crude oil tanker of 300,000 DWT operating in the Thanh Hoa area and largest tanker which arrives in and departs from each area (Figure 1 and Table 1).

Maximum oil spill and oil groups for OSRD and OSRC estimation

Calculating maximum amount of oil spill

According to IPIECA’s recommendations (IPIECA 2000), the largest oil spill from a tanker is equivalent to the full amount of oil contained in two cargo tanks of oil tanker. For target tanker of 300,000 DWT, the volume of central cargo oil tank is 30,000 m³, so the amount of the largest oil spill may be 60,000 m³. This calculation is based on the historical statistics of oil spill before the year of 2000 (IPIECA 2000). However, the tank size, tank arrangement, and hull dimensions of the oil tanker have been changed significantly till now. Besides, the seafarer’s skills for ship operation are remarkably supported by the development of science and technology. As a result, the incident rate tends to decrease in both the number of cases and the amount of oil spill (ITOPF 2017).

Type of oil group

Vietnam exploits 17 types of crude oil at domestic oil fields and imports a type of crude oil from Algeria to provide Dung Quat oil refinery with raw material for production. Crude oil from Oil Group I is subject to rapid natural dissipation and completely dissipates in 6 days after spill.

Vietnamese oil has a high freezing point of temperature, which fluctuates from 20 to 39 with high paraffin content, and its viscosity at 50 ranges from 6.05 to 65.72 mms (Le et al. 2016). Nghi Son oil refinery imports crude oil from Kuwait for production and supplies petroleum products for domestic market as well as for export. In spite of many ways to classify the types of oil, the method of dividing oils into four groups is used in this study as shown in Table 2.
In Vietnamese sea areas, most of oils have been transported in oil group II, III, and IV. Therefore, it is reasonable to select these three oil groups to estimate OSRD and OSRC of each area and region in Vietnam.

### The criteria of OSRD and OSRC in advanced marine countries

In response to oil spill incident, the maximum oil discharge should be estimated and the appropriate OSR capability is secured. However, it is unreasonable to set a certain level of OSR goal and apply it uniformly to all sea areas because the maximum oil discharge depends on the situation of oil spill incidents, the size of the vessel, the type of incident, and the place of incident. For this reason, the maximum amount of oil discharge is estimated differently according to the characteristics of the sea area and may be used to allocate and place the oil recovery equipment and response personnel as much as possible near the high risk areas of oil spill. It is difficult to judge the superiority of regional OSR capability of a certain country by simply comparing the level of OSR goal between countries. However, the comparison of national or regional OSRC between countries may show the rationality and validity of national or regional OSRC capability of a country to some extent.

### USA

In the USA, a vessel owner or operator, as applicable under Oil Pollution Act (OPA, 90) and 33 CFR (Code of Federal Regulations) Part 155 (USCG 2008a, 2008b), must identify and ensure, by contract or other approved means, that sufficient response resources are available to respond to the WCD of oil to the maximum extent practicable. 33 CFR Appendix B to Part 155 (Determining and Evaluating Required Response Resources for Vessel Response Plans) describes “Determining Response Resources Required for the Maximum Most Probable Discharge” in Section 4, “Determining Response Resources Required for the Worst Case Discharge to the Maximum Extent Practicable” in Section 5, “Determining Effective Daily Recovery Capacity for Oil Recovery Devices” in Section 6, and “Calculating the Worst Case Discharge Planning Volumes” in Section 7 (USCG 2008a).

Accordingly, it is assumed that the oil tankers operating in the sea area are subject to the maximum outflow of oil, and all the cargo loaded (ACL: t or kL [or bbl]) on the accident vessel is discharged. The oil recovery period at sea is from 4 to 10 days, depending on type of oil and spill site as near shore, offshore, and open ocean and the daily working time is based on 24 h. Table 3 shows the number of working days per pollution incident and the percentage of pollution removal by type of oil. Marine oil pollution control plans are set differently depending on the type of oil and the location of incident.

A vessel owner or operator must plan for a response to a vessel’s WCD oil planning volume which is calculated through the application of factors such as emulsification factor ($E_f$) in Table 2 and the percentage of floating oil recovery $P$ (%) in Table 3 because the planning for on-water recovery must take into account a loss of some oil to the environment due to evaporation and natural dissipation, potential increases in volume due to emulsification, and the potential for deposit of some oil on the shoreline (USCG 2008a).

### Table 1. The largest oil tankers arriving at and departing from coastal provinces and port areas in Vietnam.

| Province          | Port area            | Largest oil tanker (DWT) |
|-------------------|----------------------|--------------------------|
| Quang Ninh        | Cai Lan Oil Port     | 40,000                   |
| Hai Phong         | BC Petec, PTSC Dinh Vu | 20,000               |
| Thai Binh         | Tien Hai Gas field  | –                        |
| Thanh Hoa         | SPM Nghe Son (oil plant) | 300,000               |
| Nghe An           | DKC Oil Port        | 30,000                   |
| Ha Tinh           | Vung Ang Total Storage Oil | 18,000              |
| Quang Binh        | Gianh River Oil Port | 1000                     |
| Thua Thien        | Thuan An Oil Port   | 2000                     |
| Hue               | My Khe Oil Port      | 30,000                   |
| Quang Nga         | SPM Dung Quat (oil plant) | 150,000               |
| Binh Minh         | Quy Nhon Oil Port   | 10,000                   |
| Phu Yen           | Vung Ro Port        | 10,000                   |
| Khanh Hoa         | Van Phong Port      | 150,000                  |
|                   | Mui Chut Oil Port   | 10,000                   |
| Ba Ria–Vung       | Cai Mep Oil Port    | 50,000                   |
| Tau, Dong         | PVC Port            | 50,000                   |
| Hai Nha           | Long Son Port       | 30,000                   |
|                  | PTSC Port           | 10,000                   |
|                  | Phu My Electric Co. Oil Port | 10,000           |
|                  | K2 Oil Port         | 7000                     |
|                  | 09 Oil and gas fields Rong Doi, Rang | 150,000     |
|                  | Dong, Hong Ngoc, Lan Tay, Su Tu | 300,000*           |
|                  | Den, Dai Hung, Chi Linh, Ba Vi, Vietgopetro01 |               |
| Ho Chi Minh City  | Nha Be Oil Port     | 20,000                   |
|                  | Peotechim Oil Port  | 25,000                   |
|                  | Sai Gon Petro Oil Port | 25,000             |
|                  | Cat Lai Oil Refinery | 32,000                  |
| Can Tho           | Can Tho Oil and Gas Port | 5000                |
| Ca Mau            | Song Doc Oil Field  | 120,000                  |

* International Oil Tankers pass through

### Figure 2. The estimated mean oil outflow as a function of vessel deadweight (IMO probabilistic methodology).

In Vietnamese sea areas, most of oils have been transported in oil group II, III, and IV. Therefore, it is reasonable to select these three oil groups to estimate OSRD and OSRC of each area and region in Vietnam.

The criteria of OSRD and OSRC in advanced marine countries

In response to oil spill incident, the maximum oil discharge should be estimated and the appropriate OSR capability is secured. However, it is unreasonable to set a certain level of OSR goal and apply it uniformly to all sea areas because the maximum oil discharge depends on the situation of oil spill incidents, the size of the vessel, the type of incident, and the place of incident. For this reason, the maximum amount of oil discharge is estimated differently according to the characteristics of the sea area and may be used to allocate and place the oil recovery equipment and response personnel as much as possible near the high risk areas of oil spill. It is difficult to judge the superiority of regional OSR capability of a certain country by simply comparing the level of OSR goal between countries. However, the comparison of national or regional OSRC between countries may show the rationality and validity of national or regional OSRC capability of a country to some extent.
General formula to determine planning volume:  
(Planning volume) = (capacity) × (% from Table 3) × (emulsification factor from Table 2)  
Thus, OSRD (t or kL) is expressed by formula (1):  
\[
\text{OSRD} = \text{ACL} \times P(\%) \times E_f  
\]  
(1)

This adjusted volume or the above OSRD is multiplied by the on-water oil recovery resource mobilization factor found in Table 4 from the appropriate operating area and response tier to determine the total on-water oil recovery capacity in barrels per day that must be identified or contracted for to arrive on scene within the applicable time for each response tier.

Determining required resources for on-water recovery for each tier using mobilization factors:

(Barrel per day on-water recovery requirements) = (on-water planning volume as calculated above) × (mobilization factor from Table 4).

Thus, Daily OSRD (t/day or kL/day) or the required total on-water recovery capacity (barrels per day) is determined by the on-water oil recovery resource mobilization factor (\(M_r \text{ day}^{-1}\)) using the expression (2):

\[
\text{Daily OSRD} = \text{ACL} \times P(\%) \times E_f \times M_r  
\]  
(2)

For example, if the oil spill incident occurs from an oil tanker carrying crude oil of Group III in near shore area, from the spilled oil, up to 30% will evaporate on sea surface, 50% will be recovered through response on water, and 50% will be recovered or treated through shoreline cleanup (4 days, 24 h/day), as shown in Table 3.

However, the target value of the control amount exceeds 100% (130%), it means that it can be applied differently depending on the marine and weather conditions, and other factors.

Table 4 specifies three tiers. For higher volume port areas, the contracted tiers of resources must be located such that they can arrive on scene within 12, 36, and 60 h of the discovery of an oil discharge. For the Great Lakes, these tiers are 18, 42, and 66 h. For rivers and canals, inland, nearshore, and offshore, these tiers are 24, 48, and 72 h. For the open ocean area, these tiers are 24, 48, and 72 h with an additional travel time allowance of 1 h for every additional 5 nautical miles from shore. For non-tank vessels, only Tier 1 is specified (USCG 2008a).

Additionally, the effective daily recovery capacity (EDRC) (\(R: \text{t/day or kL/day}\)) is expressed as the following expression (3):

\[
R = T \times 24 \times E  
\]  
(3)

where \(T (\text{t/h or kL/h})\) is throughput rate in barrels per hour (nameplate capacity); 24 means 24 h per day; and \(E\) is 20% efficiency factor (or lower factor as determined by the coast guard).

For example, if the oil spill incident occurs from an oil tanker carrying 100,000 t of crude oil of Group III in near shore of the State of Washington, from the spilled oil, up to 30% will evaporate on sea surface, 50% will be recovered through response on water, and 50% will be recovered or treated through shoreline cleanup (4 days, 24 h/day), as shown in Table 3.

According to Western Response Resource List (Scott et al. 2014), effective daily recovery capacity of the State of Washington is 51,434 t/day.

Planning volumes for on-water recovery:

Near shore 100,000 × 50% × 2.0 = 100,000 t (or kL)
The daily OSRD for near shore is 40,000 t/day (or kL/day) (=100,000 × 50% × 2.0 × 0.4). The aOSRD for 4 operating days is 160,000 t (or kL) (=100,000 × 50% × 2.0 × 0.4 × 4).

Obviously, the actual daily OSRC (adOSRC) of the State of Washington (51,434 t/day) is sufficient and enough to cover the daily OSRD (40,000 t/day) for the oil spill incident from an oil tanker carrying 100,000 t of crude oil of Group III in near shore.

**Canada**

The oil recovery system of Canada is generally similar to that of USA. In accordance with the Pollution Control Act, which is based on the Canada Shipping...
Act (CSA) and the National Pollution Control System, ship owner and ship user must take necessary measures in the preparedness for oil pollution incidents, and the OSR operation is to be carried out by the certified response organization. Response organization means a qualified person to whom the Minister of Transport issues a certificate of designation under subsection 169(1) of CSA. Every prescribed vessel shall have an arrangement with a response organization in respect of a quantity of oil that is at least equal to the total amount of oil that the vessel carries, both as cargo and as fuel, to a prescribed maximum quantity, and in respect of waters where the vessel navigates or engages in a marine activity. The Minister of Transport may, in respect of any geographic area and in respect of a prescribed quantity of oil, issue a certificate of designation as a response organization to a qualified person who makes an application. In Canada, the responses to marine pollution incidents are classified into four tiers according to the frequency of oil spill occurrence, the location of oil spill, and the travel time or distance from shore to spill site. According to Canadian Coast Guard (CCG 1995, 2011), the target vessel is oil carrier which operates in Canadian jurisdictional sea area, with maximum amount of oil discharge of 10,000 t corresponding to tier 4. OSRC in Canada was distributed differently according to region for 10 operational days (Table 5).

EDRC (t/day or kL/day) is obtained by formula (4):

$$EDRC = T \times 24 \times E$$  \hspace{1cm} (4)

where $T$ (t/h or kL/h) is skimmer’s throughput rate; 24 means 24 h working per day; and $E$ is an efficiency factor set at 20% (or 0.2).

For example, a tanker incident spills about 10,000 t in the sea area of Point Tupper. Regional OSRD of Point Tupper is 4000 t (40%) onshore, and 6000 t (60%) on-water (40% from Sheltered sea and 20% from Exposed sea).

### Table 3. Removal capacity planning table (USSG, 2008a).

| Spill location | Sustainable on-water oil recovery | Near Shore/Inland/Great lakes 4 days | Offshore 6 days | Open Ocean 10 days |
|----------------|----------------------------------|------------------------------------|----------------|-------------------|
| Oil group      | % Natural dissipation | % Oil on shore | % Oil on shore | % Oil on shore |
| Nonpersistent | 80                  | 10                   | 5                  | 5                 |
| Light crude    | 50                  | 20                   | 25                 | 25                |
| Medium crude   | 30                  | 50                   | 60                 | 60                |
| Heavy crude    | 10                  | 70                   | 75                 | 75                |

*Note: Percentage may not sum to 100; reflects enhanced on-water recovery capacity.

*Included in table for continuity; no planning required.

### Table 4. On-water oil recovery resource mobilization factors (USCG 2008a).

| Area        | Tier 1 | Tier 2 | Tier 3 |
|-------------|--------|--------|--------|
| Nearshore   | 0.15   | 0.25   | 0.40   |
| Offshore    | 0.10   | 0.165  | 0.21   |
| Ocean       | 0.06   | 0.10   | 0.12   |

### Table 5. Regional pollution response percentage depending on spill site in Canada for 10 days (CCG 1995).

| Pollution location | Onshore response (%) | Sheltered sea response (%) | Exposed sea response (%) |
|--------------------|----------------------|---------------------------|--------------------------|
| Point Tupper       | 40                   | 40                        | 20                       |
| Halifax            | 40                   | 30                        | 30                       |
| Quebec city        | 60                   | 30                        | 10                       |
| Vancouver          | 40                   | 40                        | 20                       |
| Montreal           | 70                   | 30                        | 0                        |
| Nanticoke          | 50                   | 30                        | 20                       |
| Holyrood           | 40                   | 40                        | 20                       |
from Unsheltered sea) for 10 days. Therefore, total amount of effective oil spill recovery is required to be 6400 t for 10 days, which includes about 400 t through shoreline recovery by flotation machine (appropriate 10%), and about 6000 t through the total of on-water recovery (sheltered and unsheltered seas). Daily OSRD or total amount of on-water oil recovery capacity per day is 640 t/day, namely 600 t/day (60%) by on-water recovery and 40 t/day (10%) by shoreline recovery.

**Japan**

Japan has a regional approach to the OSR and control system which is similar to those in the United States and Canada. The maximum discharge oil volume of marine spill incident scenario is set in RCP in Japan, and the required amount of on-water oil recovery or OSRD in response to the maximum discharge oil volume is prescribed. In the case of Tokyo Bay, the volume of oil spill caused by a collision between a tanker and another vessel in the vicinity of a harbor tanker mooring facility is adopted as a maximum oil spill in the scenario. The maximum oil spill incident and the response criteria for Tokyo Bay are based on oil tanker of 260,000 DWT, and the maximum amount of oil spill is assumed to be 23,000 kl or about 9% of total oil cargo loaded on board tanker (JCG 2017). Japanese method of discharge oil quantity calculation is that the maximum oil spill is simply recovered and treated at sea for 2–3 days from the occurrence of oil spill incident without consideration of the weathering process of the spilled oil and the discrimination between onshore response and on-water response, and marine OSR work is to be conducted for 12 h for a day in Japan. Japanese OSR and control method aims at recovering 80% of the spilled oil from sea surface with mechanical recovery by oil skimmers and oil booms, and at treating 20% of the spilled oil on water with sorption cleanup by sorbents and with chemical dispersion by dispersants. It is judged that the nominal oil recovery capacity of the recovery device is regarded as the effective OSRC because there is no formula in Japan, and the factors of efficiency and mobilization are not considered in Japan. Therefore, EDRC (t/day or kL/day) of oil recovery system can be calculated in Japan by the following formula (5).

\[
EDRC = T \times 12
\]

where \( T \) (t/h or kL/h) is the nominal throughput rate on the name plate of oil skimmer; 12 means 12 h of working per day.

For WCD instance of 23,000 kL of crude oil spill from 260,000 DWT oil tanker in the Tokyo Bay area, the OSRD or the required amount of oil spill recovery for 2 or 3 days is 18,400 kL (=23,000 kL \times 80%).

**Korea**

Korea has experienced a significant number of oil spills such as the M/V Keum Dong No.5 oil spill incident in 1993, the Sea Prince oil spill incident in 1995. Especially, the VLCC Hebei Spirit spilled about 10,800 t of three different crude oils in 2007. The marine oil spill incident has a wide range of consequences on extensive areas of fisheries, marine, and coastal resources as well as socioeconomic aspects. In Korea, the target vessel is regional largest tanker (300,000 DWT). Maximum amount of regional oil spill is assumed to be 45,000 kl. During marine OSR for 3 days, a third (15,000 kL) of maximum oil spillage is assumed to dissipate through natural weathering processes such as evaporation, another third (15,000 kL) to reach the shore and be treated through shoreline cleanup, and the other a third (15,000 kL) to be recovered from the sea surface by mechanical equipment. Regional OSRD was estimated to be 7500 kl, respectively, for Daesan area, Yeosu area, and Ulsan area, and National OSRD or the required total amount of oil spill recovery was summed up 22,500 kL (=7500 kL \times 3) in Korea (Ha 2014).

National recovery capacity (t or kL) was calculated in consideration of mechanical efficiency, mobilization rate and operating capability of response personnel, after calculating mechanical recovery capacity of oil recovery ships and oil skimmers (Lee 2001). And then, the mechanical efficiency factor and operating efficiency factor were grouped into the following expression (6):

\[
NRC = T \times (3 \times 8) \times 0.2 \times 0.33
\]

where \( T \) is total hourly recovery capacity (kL/h) of all oil recovery devices in Korea; (3 days × 8 h/day) means total working hours for 3 days; 0.2 is mechanical efficiency factor; and 0.33 is operating efficiency factor.

**Advanced marine countries**

Table 6 shows the methods of OSRD estimation including the WCD from the largest oil tanker and examples of regional OSRD in four countries such as USA, Canada, Japan, and Korea. The regional OSRD of

| Nation | WCD | OSRD | Examples of regional OSRD |
|--------|-----|------|---------------------------|
| USA    | ACL | ACL \times P \times Ef \times m | 40,000 t State of Washington |
| Canada | 10,000 t | 64% of WCD | 46,600 kL Point Tupper |
| Japan  | 23,000 kL | 80% of WCD | 18,400 kL Tokyo Bay |
| Korea  | 45,000 kL | 50% of 1/3 WCD | 15,794 t Any region |

Note: 1 mt = 1.165 cubic meter (kiloliter – kL). Source: opec.org.
USA is the highest value (40,000 t) because WCD in USA is assumed as all the oil cargo loaded on oil tanker. Interestingly, only USA considers the emulsification factor in the estimation of OSRD, because of general formula to determine planning volume: (planning volume) = (capacity) × (% from Table 3) × (emulsification factor from Table 2). Canada, Japan, and Korea have selected their own specific WCD for the specified region as shown in Table 6. For the estimation of OSRD, USA and Canada have considered the percentage of WCD depending on the type of oil group and the geographic area in which oil tanker operates, while Japan and Korea have selected one value for all of oil groups without consideration of geographic area.

Methods of Vietnamese OSRD and OSRC estimation

The estimation of Vietnamese OSRD

Considering the calculation methods of a vessel’s WCD oil planning volume and the required total on-water recovery capacity (barrels per day) in USA, and the conditions in Vietnam, the following formulas (7) and (8) are proposed and used for the calculation of OSRD (t) and actual daily OSRD (adOSRD: t/day) in Vietnam.

\[
\text{OSRD} = Q_{\text{max}} \times P_k \times E_f \quad (7)
\]

\[
\text{adOSRD} = Q_{\text{max}} \times P_k \times E_f \times m \quad (8)
\]

where \(Q_{\text{max}}\) (t or kL) means the maximum amount of marine oil spill by area (WCD); \(P_k\) (%) means the percentage of oil remaining on the surface of water; \(E_f\) means emulsification factor; and \(m\) (day\(^{-1}\)) means mobilization factor.

\(aOSRD\) (t or kL) for the specified period may be obtained through the multiplication of \(adOSRD\) by the period of days (\(aOSRD = adOSRD \times \text{days}\)).

Maximum amount of oil spill by area \((Q_{\text{max}})\)

\(Q_{\text{max}}\) is the estimated maximum amount of oil spill by area. \(Q_{\text{max}}\) can be estimated by using IMO methodologies (IMO 2003, 2004) combined with the largest tanker in the arrival and departure areas of Vietnam (Table 1).

Coastal Vietnam can be divided into three regions (NOSRCEN, SOSRCEM, NASOS) where the greatest oil spill incident by oil tanker is likely to occur. The NOSRCEN is subdivided into Hai Phong, Thanh Hoa, and Ha Tinh areas, the SOSRCEM into Da Nang, Quang Ngai, Khanh Hoa areas, and the NASOS into Vung Tau and Ca Mau areas (Figure 3).

\(Q_{\text{max}}\) figures of NOSRCEN, SOSRCEM, and NASOS regions in Vietnam are 53,700, 49,500, and 63,000 t, respectively, and the types of oil group are II, III, and IV as shown in Figure 3 (Phan 2017) and Table 7. Because the oil outflow depends on various factors such as the type of incident, the type of oil, sea conditions, etc., these \(Q_{\text{max}}\) figures are supposed to be approximate numbers and may have some errors of 10–15% (Smailys and Cesnauskis 2006).

Percentage of oil remaining on-water \((P_k)\)

In Korea, a third of \(Q_{\text{max}}\) is supposed to be recovered from the surface of water. However, there are some differences in \(P_k\) between the types of oil group. The

Table 7. The estimated maximum amount \((Q_{\text{max}})\) of oil spill and the type of oil group by area and by region in Vietnam (Phan 2017).

| Region   | Area         | Type of oil group | Max. amount of oil spill (t) |
|----------|--------------|-------------------|-----------------------------|
| NOSRCEN  | Hai Phong    | II                | 6000                        |
|          | Thanh Hoa    | IV                | 45,000                      |
|          | Ha Tinh      | II                | 2700                        |
|          | (Sum)        |                   | 53,700                      |
| SOSRCEM  | Da Nang      | II                | 4500                        |
|          | Quang Ngai   | III               | 22,500                      |
|          | Khanh Hoa    | III               | 22,500                      |
|          | (Sum)        |                   | 49,500                      |
| NASOS    | Vung Tau     | III               | 45,000                      |
|          | Ca Mau       | III               | 18,000                      |
|          | (Sum)        |                   | 63,000                      |
| Total (T)|              |                   | 166,200                     |
percentage of oil remaining on the surface of sea water \( (P_s) \) depends on the number of operating day \( k \) \((k = 1, 2, 3, \ldots, d)\), the physical characteristics of oil, the speeds and directions of wind and current, air and water temperatures, seasons (winter and summer), etc. The natural dissipations such as evaporation and dispersion and various physical characteristics of oil such as density and viscosity may have influence on the fate and the behavior of oil spills at sea.

**Emulsification factor \((E_f)\)**

Water-in-oil emulsion can be formed within a few hours with low viscosity oil, but it usually takes several days to form water-in-oil emulsion with viscous oils. The water-in-oil emulsion is generally very viscous and more persistent than the original oil. It is often referred to as “chocolate mousse” because of its consistency. The formation of these water-in-oil emulsions can increase the volume of the spilled oil by a factor of up to 4 times. This slows and delays other oil weathering processes and can complicate the marine OSR. Emulsification factor depends on the type of oil group as shown in Table 2.

**Mobilization factor \((m)\)**

In USA, for higher volume port areas, the on-water oil recovery resources must be located such that they can arrive on scene within 12, 36, and 60 h of the discovery of an oil discharge; 18, 42, and 66 h for the Great Lakes, 24, 48, and 72 h for rivers and canals, inland, nearshore, and offshore, and 24, 48, and 72 h for the open ocean area with an additional travel time allowance of 1 h for every additional 5 nautical miles from shore (USCG 2008a). In case the on-water oil recovery resources can arrive on scene within 12, 24, 36, 60, and 72 h, respectively, from the time of the discovery of an oil discharge, mobilization factors \((\text{day}^{-1})\) are to be 2.00, 1.00, 0.67, 0.40, and 0.33, respectively. Mobilization factor \((m)\) is an important term in formulas (8) and (10), has influence on the estimations of \(a\text{OSRD}\) and \(a\text{OSRC}\), and is closely related to the allocation or placement of oil recovery devices over a certain area or region. In consideration of Vietnamese current conditions of marine and land traffics, distance between facilities, etc. and the cases of USA, mobilization factors are designed to be in the range of 0.12–0.40 as indicated in Table 8.

**The estimation of Vietnamese OSRC**

Considering the calculation methods of OSRC in advanced marine countries and the relevant conditions in Vietnam, OSRC \((t)\) and \(a\text{OSRC} \ (t/day)\) can be calculated by the following formulas (9) and (10):

\[
\text{OSRC} = T \times d \times h \times e
\]

\[
\text{adOSRD} = T \times d \times h \times e \times m
\]

where \(T \ (\text{t/h})\) is total nominal oil recovery rate of all recovery devices in a specified area or region, \(d \ (\text{day})\) is the number of operating day, \(h \ (\text{h/day})\) is working time per day, \(e \) is mechanical efficiency factor, and \(m \ (\text{day}^{-1})\) is mobilization factor.

\(a\text{OSRC} \ (t \text{ or } \text{kL})\) for the specified period may be obtained through the multiplication of \(a\text{OSRD}\) by the period of working days \((a\text{OSRC} = a\text{OSRD} \times \text{working days})\).

**Total nominal oil recovery rate \((T)\)**

Total nominal oil recovery rate \((\text{t/h})\) means the summation of hourly throughput rates of all oil recovery devices such as oil skimmers in the specified area or region. The throughput rate is displayed on the nameplate of oil recovery device by the manufacturer. Nominal recovery rates of NOSRCEN, SOSRCEN, and NASOS regions in Vietnam are 385, 380, and 888 m³/h, respectively, as shown in Table 8.

**Operating day \((d)\)**

Operating day, \(d\) is the number of operational day required to remove oil from the surface of sea. \(d\) is not constant and is variable depending on the location of oil spill incident, the type of oil, the weather conditions, the type and performance of the recovery devices, and the skill of responders. In response to the maximum amount of oil spill, the percentages of on-water oil recovery and shoreline oil recovery are different from country to country, and the respective countries determine how many operating days for on-water oil recovery are required according to their respective criteria and their own conditions expected in the geographic area in which a vessel operates. In the USA, the number of operating day is 4–10 days.
according to the geographic area of oil spill incident, 10 days in Canada, 2–3 days in Japan, and 3 days in Korea. The number of operating day is not based on the time of oil spill occurrence but can be interpreted as an operation period from the time when the initial equipment arrives at the spill site and actual recovery begins. The influence of oil decreases greatly as the physical and chemical properties of the spilled oil change rapidly with the lapse of time. It is desirable that marine OSR should be faster and more efficient.

### Working time per day (h)

Ideally, working time should be 24 h per day. However, the variability of the weather and sea conditions, the movement of oil slick, the changeability of oil properties by weathering process, the skill of responders, oil recovery efficiency, the maintenance or replacement at the time of equipment failure, etc. lead to the fact that it is impossible to operate the oil recovery devices for 24 h per day. Advanced marine countries have a standard of operating day that is suitable for their own conditions. Working time per day in Vietnam is characterized by the weathering of two seasons (winter and summer). Working time per day in summer (May–September) is longer than that in winter (October–April). Through the experiences of marine oil spill responders in Vietnam and Korea, it is almost impossible to monitor the track of oil slick at night, and it is practical to contain and recover the spilled oil by booms and skimmers from sea surface in the daytime. Working time per day in Vietnam is proposed to be 8 h per day from 07:00 to 17:00 in winter and from 08:00 to 18:00 in summer, considering the rest from responder’s fatigue for 2 h a day.

### Mechanical efficiency (ε)

Advanced marine countries apply the effective elements to the oil recovery efficiency of equipment such as oil skimmer. The mechanical properties, weather conditions, water conditions, emulsion, etc. are included in mechanical efficiency in a comprehensive way. Therefore, more practically, 20% is applied to the mechanical efficiency (ε) in Vietnam, the same as the criteria of mechanical efficiency in USA, Canada, and Korea.

Vietnamese adOSRC can be calculated by the following formula (11), considering operating days and mobilization factors shown in Table 9.

\[
adOSRC = \begin{cases} 
2.80T & \text{for 2 operating days} \\
1.680T & \text{for 3 operating days} \\
2.112T & \text{for 4 operating days} \\
2.016T & \text{for 5 operating days} \\
1.920T & \text{for 6 operating days} \\
\end{cases} 
\]  

(11)

Therefore, Vietnamese aOSRC can be calculated by the following formula (12).

\[
aOSRC = \begin{cases} 
2.560T & \text{for 2 operating days} \\
5.040T & \text{for 3 operating days} \\
8.448T & \text{for 4 operating days} \\
12.096T & \text{for 5 operating days} \\
19.200T & \text{for 6 operating days} \\
\end{cases} 
\]  

(12)

Table 9 shows the proposed scenario for the recovery of floating oil from sea surface by area in Vietnam, which is suggested on the basis of Vietnamese current conditions, considering the relevant criteria of marine developed countries in general and the removal capacity planning table of USA (USCG 2008a) in particular.

### Results of OSRD and OSRC estimation

#### Vietnamese OSRD

Vietnamese OSRDs by area and by region are estimated using formula (7) combined with the estimated maximum amount of oil spill (Q_{\text{max}}) in Figure 3, the type of oil group (I, II, III, and IV) in Table 7, emulsification factor (E_i) in Table 2, and the percentage of oil remaining on-water (P_{\text{on}}) in Table 9.

Table 10 shows that, for 4 operating days, the estimated OSRDs of Thanh Hoa and Vung Tau areas are the highest values, peaking 56,700 t (25.8%) and 63,000 t (28.7%), respectively, while the estimated OSRD of Ha Tinh area is the lowest value, 2430 t (1.1%). For 4 operating days, the estimated OSRD of NASOS region is the highest value, peaking 88,200 t.

### Table 9. Proposed scenario for the recovery of floating oil from sea surface by area in Vietnam.

| Spill location | High priority protected areas | Medium priority protected areas | Low priority protected areas | Offshore | Open ocean |
|---------------|-------------------------------|---------------------------------|-----------------------------|----------|-----------|
| Sustainable on-water oil recovery | 2 days | 3 days | 4 days | 6 days | 10 days |
| Mobilization efficiency | 0.40 | 0.35 | 0.33 | 0.21 | 0.12 |
| Oil group | % Recovery on-water |
| I | 20 |
| Nonpersistent oil | 20 |
| II | 70 |
| Light crudes and diesel products | 60 |
| III | 90 |
| Medium crudes and intermediate products | 80 |
| IV | 95 |
| Heavy crudes and residual products | 95 |

This table presents an estimate average behavior of each group that depends on oil properties and environmental conditions at the time of the spill.
As the number of operating day increases, the OSRDs of area and of region decrease because the cumulated natural dissipation such as evaporation and dispersion becomes larger with the lapse of time.

National OSRD of Vietnam, which is the sum of 3 regional OSRDs or the sum of 9 areal OSRDs, may be in the range from 87,876 t for 10 operating days to 270,882 t for 2 operating days.

**Vietnamese aOSRD**

Vietnamese daily OSRDs by area and by region are estimated using formula (8) combined with the estimated maximum amount of oil spill ($Q_{max}$) in Figure 3, the type of oil group (II, III, and IV) in Table 7, emulsification factor ($E_f$) in Table 2, and the percentage of oil remaining on-water ($P_k$) and mobilization factor ($m$) in Table 9. Then aOSRD is calculated through the multiplication of daily OSRD by the number of operating days in Table 9.

Table 11 shows that, for 4 operating days, the estimated aOSRDs of Thanh Hoa and Vung Tau areas are the highest values, peaking 74,844 t (25.8%) and 83,160 t (28.7%), respectively, while the estimated aOSRD of Ha Tinh area is the lowest value, 3208 t (1.1%). For 4 operating days, the estimated aOSRD of NASOS region is the highest value, peaking 116,424 t (40.1%), while the estimated aOSRD of NOSRCEN region is the lowest value, 85,180 t (29.4%).

As the number of operating day increases, aOSRDs of area and of region decrease with the lapse of time, while the difference between OSRD and aOSRD decreases as the number of operating day increases except the case of 2 operating days. This implies that the proposed scenario for recovery of floating oil in Table 9 is necessary to be reviewed and adjusted more finely and elaborately.

National aOSRD of Vietnam, which is the sum of 3 regional aOSRDs or the sum of 9 areal aOSRDs, may be in the range from 105,451 t for 10 operating days to 290,110 t for 4 operating days.

**Vietnamese OSRC**

Vietnamese OSRCs by area and by region are calculated using formula (9) combined with total nominal oil recovery rate ($T$) in Table 8, the number of operating day ($d$) in Table 9, working time per day ($h$: 8 h/day), and mechanical efficiency factor ($e$: 20%).

Table 12 shows that the calculated OSRCs of Hai Phong and Vung Tau areas are the highest values, peaking 4115 t (35.3%) and 5114 t (43.9%), respectively, for 4 operating days, while the calculated OSRCs of Ha Tinh, Khanh Hoa, and Ca Mau areas are 0 (null) for all operating days, because there are no oil recovery devices in those three areas. For 4 operating days,

| Region | Area | The number of operating day |
|--------|------|-----------------------------|
| Wood   |      | 2 days | 3 days | 4 days | 6 days | 10 days |
| NOSRCEN | Hai Phong | 7560   | 6480   | 5400   | 2700   | 1080   |
| Thanh Hoa | 59,850 | 59,850 | 56,700 | 31,500 | 31,500 |
| Ha Tinh | 3402   | 2916   | 2430   | 1215   | 486    |
| (Sum)  | 70,812 | 69,246 | 64,530 | 35,415 | 33,066 |
| SOSRCEM | Da Nang | 5670   | 4860   | 4050   | 2025   | 810    |
| Quang Ngai | 40,500 | 36,000 | 31,500 | 18,000 | 11,250 |
| Khanh Hoa | 40,500 | 36,000 | 31,500 | 18,000 | 11,250 |
| (Sum)  | 86,670 | 76,860 | 70,050 | 38,025 | 23,310 |
| NASOS  | Vung Tau | 81,000 | 72,000 | 63,000 | 36,000 | 22,500 |
| Ca Mau | 32,400 | 28,800 | 25,200 | 14,400 | 9000   |
| (Sum)  | 113,400 | 100,800 | 88,200 | 50,400 | 31,500 |
| Total  | 270,882 | 246,906 | 219,780 | 123,840 | 87,876 |

Table 11 shows that, for 4 operating days, the estimated aOSRDs of Thanh Hoa and Vung Tau areas are the highest values, peaking 74,844 t (25.8%) and 83,160 t (28.7%), respectively, while the estimated aOSRD of Ha Tinh area is the lowest value, 3208 t (1.1%). For 4 operating days, the estimated aOSRD of NASOS region is the highest value, peaking 116,424 t (40.1%), while the estimated aOSRD of NOSRCEN region is the lowest value, 85,180 t (29.4%).

As the number of operating day increases, aOSRDs of area and of region decrease with the lapse of time, while the difference between OSRD and aOSRD decreases as the number of operating day increases except the case of 2 operating days. This implies that the proposed scenario for recovery of floating oil in Table 9 is necessary to be reviewed and adjusted more finely and elaborately.

National aOSRD of Vietnam, which is the sum of 3 regional aOSRDs or the sum of 9 areal aOSRDs, may be in the range from 105,451 t for 10 operating days to 290,110 t for 4 operating days.
days, the calculated OSRC of NASOS region is the highest value, peaking 5114 t (43.9%), while the calculated OSRC of SOSRCEM region is the lowest value, 2061 t (17.7%).

As the number of operating day increases, OSRCs of area and of region increase because the cumulated OSRCs become larger with the lapse of time.

National OSRC of Vietnam, which is the sum of 3 regional OSRCs or the sum of 9 areal OSRCs, may be in the range from 5831 t for 2 operating days to 29,152 t for 10 operating days.

Vietnamese aOSRC

Vietnamese aOSRCs by area and by region are calculated using formula (12) combined with total nominal oil recovery rate ($T$) in Table 8, on the basis of proposed scenario for the recovery of floating oil from sea surface by area in Vietnam (Table 9).

Table 13 shows that the calculated aOSRCs of Hai Phong and Vung Tau areas are the highest values, peaking 5432 t (35.3%) and 6750 t (43.9%), respectively, for 4 operating days, while the calculated aOSRCs of Ha Tinh, Khanh Hoa, and Ca Mau areas are 0 (null) for all operating days, because there are no oil recovery devices in those three areas. For 4 operating days, the calculated aOSRC of NASOS region is the highest value, peaking 6750 t (43.9%), while the calculated aOSRC of SOSRCEM region is the lowest value, 2720 t (17.7%).

As the number of operating day increases, aOSRCs of area and of region increase because the cumulated aOSRCs become larger with the lapse of time.

National aOSRC of Vietnam, which is the sum of 3 regional aOSRCs or the sum of 9 areal aOSRCs, may be in the range from 4664 t for 2 operating days to 34,982 t for 10 operating days.

Comparison of the estimated OSRD and OSRC

OSRD and OSRC by area for 4 operating days

For 4 operating days, OSRC (4115 t) is smaller than OSRD (5400 t) in Hai Phong area, and OSRC (371 t) is much smaller than OSRD (56,700 t) in Thanh Hoa area. In addition, OSRC (1485 t) is smaller than OSRD (4050 t) in Da Nang area, and OSRC (576 t) is smaller than OSRD (31,500 t) by far in Quang Ngai area. Furthermore, OSRC (5114 t) is much smaller than OSRD (63,000 t) in Vung Tau area, and OSRC (0 t) is null even if OSRD is 25,200 t for 4 operating days in Ca Mau area. This means that areal OSRCs are insufficient to meet the corresponding areal OSRDs in Vietnam.

For 4 operating days, OSRD (5400 t) of Hai Phong area is much smaller than OSRD (56,700 t) in Thanh Hoa area, while OSRD (4115 t) of Hai Phong area is much greater than OSRD (371 t) of Thanh Hoa area. In addition,

Table 12. The calculated OSRCs (t) by area and by region based on the data of oil recovery devices stocks in Vietnam.

| Region     | Area        | Nominal recovery rate (t/h) | The number of operating day |
|------------|-------------|-----------------------------|-----------------------------|
|            |             | 2 days | 3 days | 4 days | 6 days | 10 days  |
| NOSRCEN    | Hai Phong   | 643    | 2058   | 3086   | 4115   | 6173     | 10,288   |
|            | Thanh Hoa   | 58     | 186    | 278    | 371    | 557      | 928      |
|            | Ha Tinh     | 0      | 0      | 0      | 0      | 0        | 0        |
|            | (Sum)       | 701    | 2244   | 3364   | 4486   | 6730     | 11,216   |
| SOSRCEN    | Da Nang     | 232    | 742    | 1114   | 1485   | 2227     | 3712     |
|            | Quang Ngai  | 90     | 288    | 432    | 576    | 864      | 1440     |
|            | Khanh Hoa   | 0      | 0      | 0      | 0      | 0        | 0        |
|            | (Sum)       | 322    | 1030   | 1546   | 2061   | 3091     | 5152     |
| NASOS      | Vung Tau    | 799    | 2557   | 3835   | 5114   | 7670     | 12,784   |
|            | Ca Mau      | 0      | 0      | 0      | 0      | 0        | 0        |
|            | (Sum)       | 799    | 2557   | 3835   | 5114   | 7670     | 12,784   |
| Total      |             | 1822   | 5831   | 8745   | 11,661 | 17,491   | 29,152   |

Table 13. The calculated actual OSRCs (t) by area and by region in Vietnam based on the data of oil recovery devices stocks and the proposed scenario.

| Region     | Area        | Nominal recovery rate (t/h) | The number of operating day |
|------------|-------------|-----------------------------|-----------------------------|
|            |             | 2 days | 3 days | 4 days | 6 days | 10 days  |
| NOSRCEN    | Hai Phong   | 643    | 1646   | 3241   | 5432   | 7778     | 12,346   |
|            | Thanh Hoa   | 58     | 149    | 292    | 490    | 702      | 1113     |
|            | Ha Tinh     | 0      | 0      | 0      | 0      | 0        | 0        |
|            | (Sum)       | 701    | 1795   | 3533   | 5922   | 8480     | 13,459   |
| SOSRCEN    | Da Nang     | 232    | 594    | 1169   | 1960   | 2806     | 4454     |
|            | Quang Ngai  | 90     | 230    | 454    | 760    | 1089     | 1728     |
|            | Khanh Hoa   | 0      | 0      | 0      | 0      | 0        | 0        |
|            | (Sum)       | 322    | 824    | 1623   | 2720   | 3895     | 6182     |
| NASOS      | Vung Tau    | 799    | 2045   | 4027   | 6750   | 9665     | 15,341   |
|            | Ca Mau      | 0      | 0      | 0      | 0      | 0        | 0        |
|            | (Sum)       | 799    | 2045   | 4027   | 6750   | 9665     | 15,341   |
| Total      |             | 1822   | 4664   | 9183   | 15,392 | 22,040   | 34,982   |
OSRD (4050 t) of Da Nang area is smaller than OSRD (31,500 t) of Quang Ngai area by far, while OSCRC (1485 t) of Da Nang area is greater than OSCRC (576 t) of Quang Ngai area for 4 operating days. This suggests that the allocations of areal OSRCs are not balanced over the relevant region in Vietnam, in view of the distribution of the corresponding areal OSRDs in the region.

**aOSRD and aOSRC by area for 4 operating days**

For 4 operating days, aOSRC (5432 t) is smaller than aOSRD (7128 t) in Hai Phong area, and aOSRC (490 t) is much smaller than aOSRD (74,844 t) in Thanh Hoa area. In addition, aOSRC (1960 t) is smaller than aOSRD (5346 t) by far in Da Nang area. Furthermore, aOSRC (760 t) is much smaller than aOSRD (41,580 t) in Quang Ngai area, and aOSRC (6750 t) is much smaller than aOSRD (83,610 t) in Vung Tau area, and aOSRC (0 t) is null even if OSRD is 33,264 t for 4 operating days in Ca Mau area. This means that areal aOSRCs are insufficient to meet the corresponding areal aOSRDs in Vietnam.

For 4 operating days, the aOSRD (7128 t) of Hai Phong area is much smaller than aOSRD (74,844 t) of Thanh Hoa area, while aOSRC (5432 t) of Hai Phong area is much greater than aOSRC (490 t) of Thanh Hoa area. In addition, aOSRD (5346 t) of Da Nang area is smaller than aOSRD (41,580 t) of Quang Ngai area by far, while aOSRC (1960 t) of Da Nang area is greater than aOSRC (760 t) of Quang Ngai area for 4 operating days. This suggests that the allocations of areal aOSRCs are not balanced over the relevant region in Vietnam, in view of the distribution of the corresponding areal aOSRDs in the region.

**OSRD and OSCRC by region for 4 operating days**

For 4 operating days, OSCRC (4486 t) is much smaller than OSRD (64,530 t) in NORSCEN region. In addition, OSCRC (2061 t) is smaller than OSRD (67,050 t) by far in SOSRCEM region. Further, OSCRC (5114 t) is much smaller than OSRD (88,200 t) in NASOS region. This means that regional OSCRCs are not enough to reach the corresponding regional OSRDs, being insufficient to meet regional OSRDs in Vietnam.

For 4 operating days, OSRD (64,530 t) of NORSCEN region is smaller than OSRD (67,050 t) of SOSRCEM region, while OSCRC (4486 t) in NORSCEN region is greater than OSCRC (2061 t) in SOSRCEM region. This suggests that the allocations of regional OSCRCs are not balanced through the nation, in view of the distribution of the corresponding regional OSRDs over the country of Vietnam.

**National OSRD and national OSCRC for 4 operating days**

For 4 operating days, national OSCRC (15,302 t) is much smaller than national OSRD (290,110 t) in Vietnam. This means that national aOSRCs are insufficient to meet national aOSRDs in Vietnam.

**Alternative plans for the improvement and reinforcement of Vietnamese marine OSCR**

It is necessary to improve and reinforce the areal, regional, and national OSCRCs or aOSRCs in conformity with the corresponding areal, regional, and national OSRDs or aOSRDs in Vietnam, and to balance properly the allocation and distribution of OSCRCs or aOSRCs by area, by region, and nationwide in Vietnam, on the basis of the scientific and quantitative estimation results. In particular, mobilization factor \( m \) is necessary to be improved (or \( m \) value is to be decreased) for the reinforcement of the area, regional, and national aOSRCs in Vietnam. In ideal case, aOSRC may approach aOSRD by improving mobilization factor \( m \) (ideally, \( m \) value becomes 1.0 for the target value), leading to the rational and proper reallocation of OSCR resources such as oil recovery devices in Vietnam.

**Conclusion**

Through the analysis of the criteria of advanced marine countries for the establishment of OSCRC, and the examination of the current conditions on marine oil transportation and offshore activities in Vietnam, Vietnamese OSRD and aOSRC are estimated quantitatively using formulas containing some items such as maximum amount of oil spill, percentage of oil remaining on-water, emulsification factor, and mobilization factor. In addition, Vietnamese OSCRC and aOSRC are calculated quantitatively using formulas containing some items such as total nominal oil
recovery rate, operating day, working time per day, mechanical efficiency, and mobilization factor, on the basis of the proposed scenario for the recovery of floating oil from sea surface in Vietnam.

The results of this study are summarized as follows:

(1) For 4 operating days, OSRDs (or aOSRDs) of Thanh Hoa and Vung Tau areas are estimated to be the highest values, peaking 56,700 t (25.8%) [or 74,844 t (25.8%)] and 63,000 t (28.7%) [or 83,160 t (28.7%)], respectively, while the estimated OSRD (or aOSRD) of Ha Tinh area is the lowest value, 2430 t (1.1%) [or 3208 t (1.1%)]. For 4 operating days, OSRD (or aOSRD) of NASOS region is estimated to be the highest value, peaking 88,200 t (40.1%) [or 116,424 t (40.1%)], while the estimated OSRD (or aOSRD) of NOSRCEM region is the lowest value, 64,530 t (29.4%) [or 85,180 t (29.4%)]. National OSRD (or aOSRD) of Vietnam, which is the sum of 3 regional OSRDs (or aOSRDs), may be in the range from 87,876 t [or 105,451 t] for 10 operating days to 270,882 t for 2 operating days (or 290,110 t for 4 operating days).

(2) OSRCs (or aOSRCs) of Hai Phong and Vung Tau areas are calculated to be the highest values, peaking 4115 t (35.3%) [or 5432 t (35.3%)] and 5114 t (43.9%) [or 6750 t (43.9%)], respectively, for 4 operating days, while the calculated OSRCs (or aOSRCs) of Ha Tinh, Khanh Hoa, and Ca Mau areas are 0 (null) for all operating days (2–10 days). For 4 operating days, OSRC (or aOSRC) of NASOS region is calculated to be the highest value, peaking 5114 t (43.9%) [or 6750 t (43.9%)], while the calculated OSRC (or aOSRC) of NOSRCEM region is the lowest value, 2061 t (17.7%) [or 2720 t (17.7%)]. National OSRC (or aOSRC) of Vietnam, which is the sum of 3 regional OSRCs (or aOSRCs), may be in the range from 5831 t (or 4664 t) for 2 operating days to 29,152 t (or 34,982 t) for 10 operating days.

(3) In comparison of OSRD (or aOSRD) with OSRC (or aOSRC), all areal and regional OSRDs (or aOSRCs) are much smaller than all the corresponding areal and regional OSRCs (or aOSRCs). Especially, OSRCs of Ca Mau area are null even if OSRD is 25,200 t for 4 operating days in Ca Mau area. In addition, national OSRCs (or aOSRC) are much smaller than National OSRD (or aOSRD) in Vietnam. This means that areal and regional OSRCs (or aOSRCs) are insufficient to meet the corresponding areal and regional OSRDs (or aOSRDs) in Vietnam.

(4) The specified areal and regional OSRDs (or aOSRDs) are smaller than other areal and regional OSRDs (or aOSRDs) by far, while other areal and regional OSRCs (or aOSRCs) are greater than the specified areal and regional OSRCs (or aOSRCs). This suggests that the allocations of areal and regional OSRCs (or aOSRCs) are not balanced over the relevant region in Vietnam, in view of the distribution of the corresponding areal and regional OSRDs (or aOSRDs).

Therefore, it is necessary to improve and reinforce the areal, regional, and national OSRCs or aOSRCs in conformity with the corresponding areal, regional, and national OSRDs or aOSRDs in Vietnam, and to balance properly the allocation and distribution of OSRCs or aOSRCs by area, by region, and nationwide in Vietnam, on the basis of the scientific and quantitative estimation results. In particular, mobilization factor (m) is necessary to be improved (or m value is to be decreased) for the reinforcement of areal, regional, and national aOSRCs in Vietnam.

The results of this study are expected to be science platform to support policy-making and contingency plan making for preparedness and response to marine oil spills in Vietnam. In the future, the more detailed researches on the development of scenario for the recovery of floating oil from the sea surface, the improvement of mobilization factor, the proper allocation of marine OSR resources over the area, the region and nationwide, and the verification of the estimated or quantified OSRDs and OSRCs are expected to be performed in Vietnam.

Disclosure statement

No potential conflict of interest was reported by the authors.

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