MATHEMATICAL MODELLING STUDY FOR SETTING UP 400 MLD DESALINATION PLANT AT PERUR, CHENNAI

PROJECT CODE: 696082021

For

Member of the Surbana Jurong Group

SMEC INDIA PVT. LTD.

GURUGRAM

NOVEMBER 2020

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Client	SMEC India Pvt Ltd., Gurugram.
Project Title	Mathematical modelling study for setting up 400 MLD Desalination Plant at Perur, Chennai.
Project Code	696082021
Abstract	CMWSSB has planned to set up a 400 MLD desalination plant at Perur. CMWSSB has nominated SMEC India Pvt Ltd., Gurugram as Project Consultant. SMEC has asked Indomer Coastal Hydraulics (P) Ltd., Chennai to carryout mathematical modelling study on dispersion of brine reject over the proposed nearshore region planned for fixing seawater intake and brine reject outfall. Accordingly, Indomer had carried out the modelling studies using DHI MIKE 21 suites to meet the required scope.
Foreword	
Document	Controlled
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1. INTRODUCTION

CMWSSB has planned to set up a 400 MLD desalination plant at Perur. CMWSSB has nominated SMEC India Pvt Ltd., Gurugram as Project Consultant. SMEC has asked Indomer Coastal Hydraulics (P) Ltd., Chennai to carryout mathematical modelling study on dispersion of brine reject over the proposed nearshore region planned for fixing seawater intake and brine reject outfall. Accordingly, Indomer had carried out the modelling studies using DHI MIKE 21 suites to meet the required scope.

Indomer Coastal Hydraulics (P) Ltd., Chennai is an ISO 9001:2015 certified organization promoted under CSIR – NIO Entrepreneurship scheme, Government of India. It also carries accreditation for preparation of Feasibility Report/ DPR – Marine sector by Consultancy Development Centre, DSIR, Ministry of Science and Technology; and NABET - QCI accreditation for carrying out EIA studies for *Sector 27: Oil & Gas Transportation pipeline (crude and refinery/petrochemical products), passing through national parks/ sanctuaries/ coral reefs/ ecologically sensitive areas including LNG terminal and Sector 33: Ports, harbours, jetties, marine terminals, breakwaters and dredging.*

The location map and satellite imagery of the project region is shown in **Fig. 1.1**.

All calendar dates are referred in Indian style as dd.mm.yy. (eg. 25.10.20 for 25th October 2020) and the time is referred to Indian Standard Time in 24 hour clock, eg. 3 P.M. is written as 1500 hrs. The WGS84 spheroid in Zone 44 is used for the presentation in this report. SI units are followed for fundamental and derived units. The depths are referred with respect to Chart Datum.

2. SCOPE OF STUDY

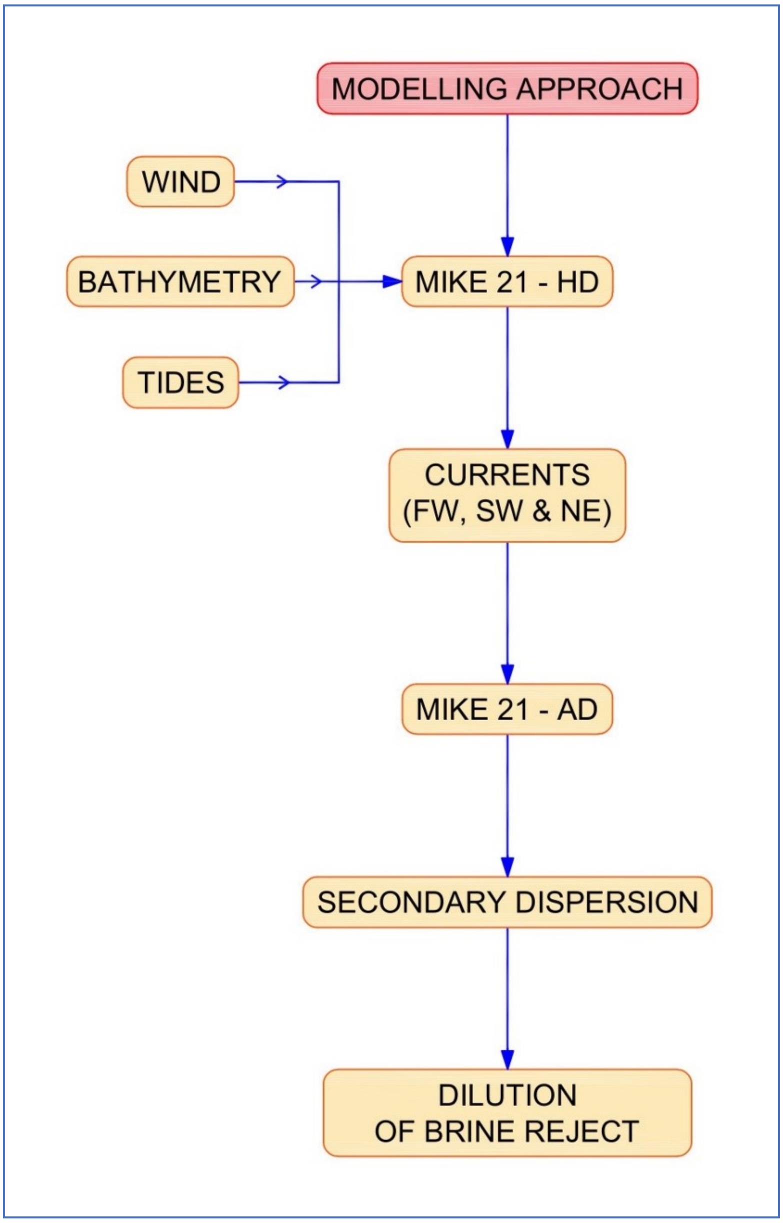
To conduct DHI-MIKE 21 -AD modelling to understand the dispersion pattern for the three outfall cases

a) *CASE I – Given in DPR – 700 m offshore*
b) *CASE II – Adopted in JICA study – 1700 m offshore*
c) *CASE III – Suggested by Indomer – 850 m offshore*

3. MODELLING APPROACH

To identify the feasible location for the discharge of brine reject at open sea, it is essential to understand the tide and flow characteristics in and around the vicinity of outfall during different tidal condition over a Spring - Neap tidal cycle. It is convenient to use mathematical modelling studies to simulate the variation of tides and currents under different tidal condition.

DHI - MIKE 21 model is comprised of the modules on *Hydrodynamic – HD and Advection Dispersion – AD.* These models have been developed by Danish Hydraulic Institute (DHI), Denmark, and are being used worldwide for many coastal engineering applications. The flow chart of the model describing the approach followed in the present study is given below.



4. SECONDARY DISPERSION – MIKE 21 MODEL

The dispersion pattern of the return water discharged into the coastal waters are simulated using the DHI - MIKE 21 Advection-Dispersion (AD) model. The flow pattern in coastal water required as input to this model is derived from the MIKE 21 Hydrodynamic (HD) model. These MIKE 21 models have been developed by Danish Hydraulic Institute (DHI), Denmark, and are being used worldwide in many coastal engineering applications.

4.1. Methodology

Units and Conventions used

Units: Units of all parameters and variables in the model study are according to international SI Units. Coordinate system: The coordinate system used for model grid generation and other horizontal positioning was based on UTM on WGS 84 spheroid. Vertical reference level: The depth information used in the tidal flow models is relative to Mean Sea Level (MSL); depths below MSL are defined negative.

Directions

Current – Ocean current directions refer to the direction towards which the flow is taking place. Directions of the flow are always given clockwise with respect to North; the Unit is degrees, where 360 degrees cover the circle. Wind - Wind directions refer to the direction from which the wind is approaching. Directions of the wind are always given clockwise with respect to North; the Unit is degrees, where 360 degrees cover the circle.

4.2. MIKE 21 Hydrodynamic (HD) model

This model is a two-dimensional hydrodynamic flow simulation model, which solves shallow-water equations for given boundary conditions to compute non-steady free-surface flow fields in response to a variety of environmental forcing and processes in natural water bodies. The environmental forcing and processes include: bottom shear stress, wind shear stress, barometric pressure gradients, Coriolis force, momentum dispersion, sources and sinks, evaporation, flooding and drying and wave radiation stresses. This model is applicable for the simulation of flow fields in natural water bodies, such as lakes, estuaries, bays, coastal areas and seas, wherever stratification can be neglected. The MIKE 21-Flow model can be used to simulate Tide, wind and Wave-driven currents.

This model uses an Alternate Direction Implicit (ADI) Finite Difference Method on staggered orthogonal grids; this model also has the option to use Finite Element Method.

The basic shallow-water equations in the Cartesian co-ordinate system solved in the MIKE 21 HD flow model are:

Continuity equation:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial X} + \frac{\partial q}{\partial Y} = S - e$$

Momentum equations in x- and y- directions:

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial X}\left[\frac{p^2}{h}\right] + \frac{\partial}{\partial Y}\left[\frac{p\,q}{h}\right] + gh\frac{\partial \zeta}{\partial X} + F_{bx} - K_a W W_X - \frac{h}{\rho_W}\frac{\partial p_a}{\partial X} - \Omega\, q - F_{EX} = S_{iX}$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial X}\left[\frac{p\,q}{h}\right] + \frac{\partial}{\partial Y}\left[\frac{q^2}{h}\right] + gh\frac{\partial \zeta}{\partial Y} + F_{by} - K_a W W_Y - \frac{h}{\rho_W}\frac{\partial p_a}{\partial Y} + \Omega p - F_{EY} = S_{iY}$$

$$F_{EX} = \left[\frac{\partial}{\partial X}\left[\varepsilon_X\, h\frac{\partial u}{\partial X}\right] + \frac{\partial}{\partial Y}\left[\varepsilon_Y\, h\,\frac{\partial u}{\partial Y}\right]\right]$$

$$F_{EY} = \left[\frac{\partial}{\partial X}\left[\varepsilon_X\, h\frac{\partial u}{\partial X}\right] + \frac{\partial}{\partial Y}\left[\varepsilon_Y\, h\frac{\partial u}{\partial Y}\right]\right]$$

$$F_{bx} = \frac{g}{C^2}\sqrt{\frac{p^2}{h^2} + \frac{q^2}{h^2}}\,\frac{p}{h}$$

$$F_{by} = \frac{g}{C^2}\sqrt{\frac{p^2}{h^2} + \frac{q^2}{h^2}}\,\frac{q}{h}$$

Symbol List:

ζ (x, y, t)	-	Water surface level above datum (m)
p(x, y, t)	-	flux density in the x-direction (m3/s/m)
q(x, y, t)	-	flux density in the y-direction (m3/s/m)
h(x, y, t)	-	water depth (m)
S	-	source magnitude per unit horizontal area (m3/s/m2)
S_{iX} , S_{iY}	-	source impulse in x and y-directions (m3/s/m2.m/s)
e	-	evaporation rate (m/s)
g	-	gravitational acceleration (m/s2)
C	-	Chezy resistance No. (m1/2/s)
Ka	-	$c_w \frac{\rho_{air}}{\rho_{Water}}$
Cw	-	wind friction factor
W, WX, WY(x, y, t)	-	wind speed and its components in x- and y-directions (m/s)
pa (x, y, t)	-	barometric pressure (Kg/m/s2)
ρw	-	density of water (kg/m3)

Ω	-	Coriolis coefficient (latitude dependent) (s-1)
ε(x, y)	-	eddy or momentum dispersion coefficient (m2/s)
x, y	-	space coordinates (m)
t	-	time (s)

4.3. Boundary conditions

The HD model is forced by the tidal water level variations along the open sea boundaries. For the generation of these boundary conditions, the MIKE 21 C-Map tide data base is used. These boundary conditions are prescribed as time series of tidal water level variations along the open boundaries of the model. If the tidal constituents along the boundaries of the model are available, then the boundary conditions are represented by:

$$h_t = A_0 + \sum_{i=1}^{n} f_i A_i \cos(\omega_i t + (v_0 + u)_i \quad g_i)$$

With:

ht	=	water level at time = t
Ao	=	mean value of the signal
Ai	=	amplitude of component i
fi	=	nodal amplitude factor of component i
ωi	=	angular frequency of component i
(v0+u)I	=	astronomic argument of component i
gi	=	phase lag of component i

4.4. MIKE 21 Advection and dispersion (AD) model

The advection-dispersion (AD) model of the MIKE 21 model suite simulates dispersion of return water in natural water bodies under the influence of the fluid transport and associated natural dispersion process. The dispersing substance may be conservative or non-conservative, inorganic or organic: e.g. salt, heat, dissolved oxygen, inorganic phosphorus, nitrogen and other such water quality parameters. Applications of the MIKE 21 AD model are in principle essential for two types of investigations, viz., i) cooling water recirculation studies for power plants and salt recirculation studies for desalination plants, and ii) water quality studies connected with sewage outfalls and non-point pollution sources.

This model determines the concentration of the dispersing substance by solving the equation of conservation of mass for both dissolved and suspended substances. The concentration of the substance is calculated at each point of a rectangular grid covering the area of interest using a two-dimensional finite difference scheme. Information on currents and water depths at each point of the grid, are provided by the MIKE 21 HD model.

Other data required in the model include effluent volume discharged, the concentration of the pollutant, and the initial & boundary conditions.

The MIKE 21 AD model solves the advection-dispersion equation for dissolved or suspended substances in two dimensions. This is the mass-conservation equation of substances discharged at source and sink points considering their decay rates,

$$\frac{\partial}{\partial t}(hc)+\frac{\partial}{\partial x}(uhc)+\frac{\partial}{\partial y}(vhc) = \frac{\partial}{\partial x}\left[hD_x\frac{\partial C}{\partial x}\right]+\frac{\partial}{\partial y}\left[hD_y\frac{\partial C}{\partial y}\right]-Fhc+S$$

Symbol list

C	-	compound concentration (arbitrary units)
u, v	-	horizontal velocity components in the x, y directions (m/s)
h	-	water depth (m)
Dx, Dy	-	dispersion coefficients in the x, y directions (m2/s)
F	-	linear decay coefficient (1/s)
S	-	Qs . (Cs – C)
Qs	-	Source / sink discharge per unit horizontal area (m3/s/ m2)
Cs	-	concentration of compound in the source / sink discharge.

Information on u, v and h at each time step is provided by the MIKE 21 HD model.

4.5. Model domain

The model domain was setup for the study region to include the finer details of the local geometry, bathymetry and other site specific conditions in the model. The coarse resolution grid covers an area of approximately 100 km x 150 km with the grid spacing of 405 m in both x and y directions. The grid comprised of approximately 91,390 computational points. The finer resolution grid covers an area of approximately 3.6 km x 10.5 km with the grid spacing of 15 m in both x and y directions. The grid comprised of approximately 1,68,941 computational points. The finer bathymetry is shown in **Fig. 4.1**.

<u>Data requirements:</u> The data for the MIKE 21 HD module is described below:

i) Bathymetry
ii) Initial Conditions:
iii) Water surface levels and
iv) Flux densities in x and y directions
v) Boundary Conditions:
vi) Water levels or flow magnitude and low direction
vii) Other Driving Forces:
viii) Wind speed and direction
ix) Source/sink discharge magnitude and speed.

Depth Schematization: Depth schematization has been made from MIKE-CMAP, a worldwide electronic chart database. This database on bathymetric data over the ocean has been developed jointly by DHI, Denmark and C-MAP, Norway. The extracted bathymetry data from CMAP have been corrected with the depths presented in Indian Naval Hydrographic Charts (NHC:313) and the bathymetry data collected by Indomer specific to the study area.

Model Input: To set and run the hydrodynamic model, the input parameters considered are the bathymetry, tides, winds, waves, bottom friction, location of discharge, quantity of discharge, ambient TDS, return brine TDS etc.

Input on wind: For the flow simulation, to represent the fair weather, it is assumed as low wind with a value of 1 m/s coming from southwest direction. In case of southwest monsoon season, higher wind speed of 10 m/s from southwest direction was introduced. For northeast monsoon period, moderate with speed of 7 m/s from northeast direction was introduced.

Volume of discharge: The volume of the brine reject released into the sea is given below.

Volume of discharge		
Nemmeli- Existing 100 MLD Plant	Perur proposed 400 MLD Plant	Nemmeli – proposed 150 MLD Plant
138 MLD	546 MLD	207 MLD
5750 m^3/hour	22750 m^3/hour	8625 m^3/hour
1.60 m^3/s	6.32 m^3/s	2.40 m^3/s

The tide induced flow field over the study area for one lunar month (29 days) were simulated using MIKE 21-HD model. Dispersion of return water in natural water bodies under the influence of the fluid transport and associated natural dispersion process was simulated using MIKE 21.

TDS: *As per client email vide dt. 01.10.2020, the ambient TDS of the seawater is considered as 39000 ppm and the return brine TDS is considered as 67000 ppm.*

4.6. Model calibration

The HD model is calibrated using the measured tides at the project location. A good agreement was observed between the simulated and measured tides. Similarly, a reasonable agreement was observed between the simulated and measured currents.

5. SIMULATIONS

i) Locations: The simulation was carried out for three different cases of location of outfall tentatively considered for Perur plant. The details are given below.

Simulation	Detail	Distance of outfall at offshore
Case I	Given in DPR	700 m
Case II	Adopted in JICA study	1700 m
Case III	Suggested by Indomer	850 m

The various locations of intake and outfall are shown in **Figs. 5.1 to 5.3**. The location coordinates and other details are given below.

Scenarios	Geographical Coordinates (WGS 84)		UTM Coordinates (Zone 44)	
	Latitude, N	Longitude, E	X (m)	Y (m)
CASE I – DPR				
Intake Distance = 1200 m from LFP	12°42'38"	80°14'26"	0417558	1405252
Outfall diffuser Length= 700 m from LFP	12°42'49"	80°14'13"	0417161	1405584
CASE II - JICA				
Intake Distance = 1150 m from DP	12°42'44"	80°14'26"	0417543	1405423
Outfall diffuser Length= 1700 m from DP	12°42'37"	80°14'43"	0418060	1405235
CASE III – SUGGESTED BY INDOMER				
Intake Distance = 1300 m from LFP	12°42'25"	80°14'25"	0417522	1404858
Outfall diffuser Length= 850 m from LFP	12°42'49"	80°14'16"	0417259	1405587

ii) Seasons: The flow field induced by tides and wind and the associated mixing of brine reject has been simulated to cover following three different seasons.

Season	Representative months
Fair Weather	February to May
Southwest monsoon	June to September
Northeast monsoon	October to January

iii) Simulation period: In each simulation, the flow field and the secondary advection – diffusion has been done for a period of one lunar month, i.e. March representing fair weather, July representing southwest monsoon and November representing northeast monsoon.

Scenarios	Fair weather	SW Monsoon	NE Monsoon
Case I	√	√	√
Case II	√	√	√
Case III	√	√	√

6. MODELLING RESULTS FOR COMBINED SCENARIOS

The secondary dispersion of the brine reject from the existing and proposed outfall locations covering spring and neap tidal phases for three different cases are given below.

Simulation	Detail	Distance of outfall at offshore
Case I	Given in DPR	700 m
Case II	Adopted in JICA study	1700 m
Case III	Suggested by Indomer	850 m

CASE I – Given in DPR – 700 m offshore

Fair weather

During the fair weather, the wind speed over the sea remains low. The sea would be relatively calm with low wave activity and very moderate currents. This will lead to relatively low mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.1(A) to 6.1(B).** The brine of resultant TDS of 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 3200 m and 41, 000 ppm at 250 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.2(A) to 6.2(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 3300 m and 41, 000 ppm at 260 m distance from the outfall.

SW monsoon

During the SW Monsoon, the wind speed over the sea remains high. The sea would remain with relatively higher wave activity and currents. This will lead to relatively high mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.3(A) to 6.3(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1200 m and 41, 000 ppm at 80 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.4(A) to 6.4(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1300 m and 41, 000 ppm at 90 m distance from the outfall.

NE monsoon

During the NE Monsoon, the wind speed over the sea remains high. The sea would remain with relatively higher wave activity and currents. This will lead to relatively high mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.5(A) to 6.5(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 2300 m and 41, 000 ppm at 90 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.6(A) to 6.6(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 2350 m and 41, 000 ppm at 100 m distance from the outfall.

CASE II – Adopted in JICA study – 1700 m offshore

Fair weather

During the fair weather, the wind speed over the sea remains low. The sea would be relatively calm with low wave activity and very moderate currents. This will lead to relatively low mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.7(A) to 6.7(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 2200 m and 41, 000 ppm at 90 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.8(A) to 6.8(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 2300 m and 41, 000 ppm at 100 m distance from the outfall.

SW monsoon

During the SW Monsoon, the wind speed over the sea remains high. The sea would remain with relatively higher wave activity and currents. This will lead to relatively high mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.9(A) to 6.9(B)**The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1100 m and 41, 000 ppm at 30 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.10(A) to 6.10(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1120 m and 41, 000 ppm at 50 m distance from the outfall.

NE monsoon

During the NE Monsoon, the wind speed over the sea remains high. The sea would remain with relatively higher wave activity and currents. This will lead to relatively high mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.11(A) to 6.11(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1500 m and 41, 000 ppm at 50 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.12(A) to 6.12(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1650 m and 41, 000 ppm at 50 m distance from the outfall.

CASE III – Suggested by Indomer – 850 m offshore

Fair weather

During the fair weather, the wind speed over the sea remains low. The sea would be relatively calm with low wave activity and very moderate currents. This will lead to relatively low mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.13(A) to 6.13(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 3000 m and 41, 000 ppm at 190 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.14(A) to 6.14(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 3250 m and 41, 000 ppm at 210 m distance from the outfall.

SW monsoon

During the SW Monsoon, the wind speed over the sea remains high. The sea would remain with relatively higher wave activity and currents. This will lead to relatively high mixing of the brine reject released into the sea. The flow conditions will vary over the lunar tidal cycle, i.e. for every tidal cycle covering two consecutive spring to neap tidal cycles for 29 days. The brine reject released into the sea also will have variable mixing pattern according to the instantaneous turbulence caused by the current speed and direction. Accordingly, the typical scenario of the dispersion on the spring tidal day and neap tidal day are extracted and summarized below.

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.15(A) to 6.15(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1150 m and 41, 000 ppm at 50 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.16(A) to 6.16(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1200 m and 41, 000 ppm at 60 m distance from the outfall.

NE monsoon

Spring tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.17(A) to 6.17(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1800 m and 41, 000 ppm at 60 m distance from the outfall.

Neap tide: The mixing pattern of the brine reject in the nearshore region are shown in **Figs. 6.18(A) to 6.18(B).** The brine of resultant TDS = 67,000 ppm, discharged in the sea undergoes dispersion and reaches the TDS of 39,000 ppm at 1900 m and 41, 000 ppm at 70 m distance from the outfall.

7. CONCLUSION

The secondary dispersion takes place due to convection currents and undergoes further dilution. Mixing zones of TDS of 39,000 ppm and 41,000 ppm for the proposed and existing outfalls resulting from the secondary dispersion study using MIKE 21 AD are given below:

Scenarios	Season	TDS (ppm)	Spring tide (m)	Neap tide (m)
CASE I	Fair weather	39000	3200	3300
	SW monsoon	39000	1200	1300
	NE monsoon	39000	2300	2350
CASE II	Fair weather	39000	2200	2300
	SW monsoon	39000	1100	1120
	NE monsoon	39000	1500	1650
CASE III	Fair weather	39000	3000	3250
	SW monsoon	39000	1150	1200
	NE monsoon	39000	1800	1900

Scenarios	Season	TDS (ppm)	Spring tide (m)	Neap tide (m)
CASE I	Fair weather	41000	250	260
	SW monsoon	41000	80	90
	NE monsoon	41000	90	100
CASE II	Fair weather	41000	90	100
	SW monsoon	41000	30	50
	NE monsoon	41000	50	50
CASE III	Fair weather	41000	190	210
	SW monsoon	41000	50	60
	NE monsoon	41000	60	70

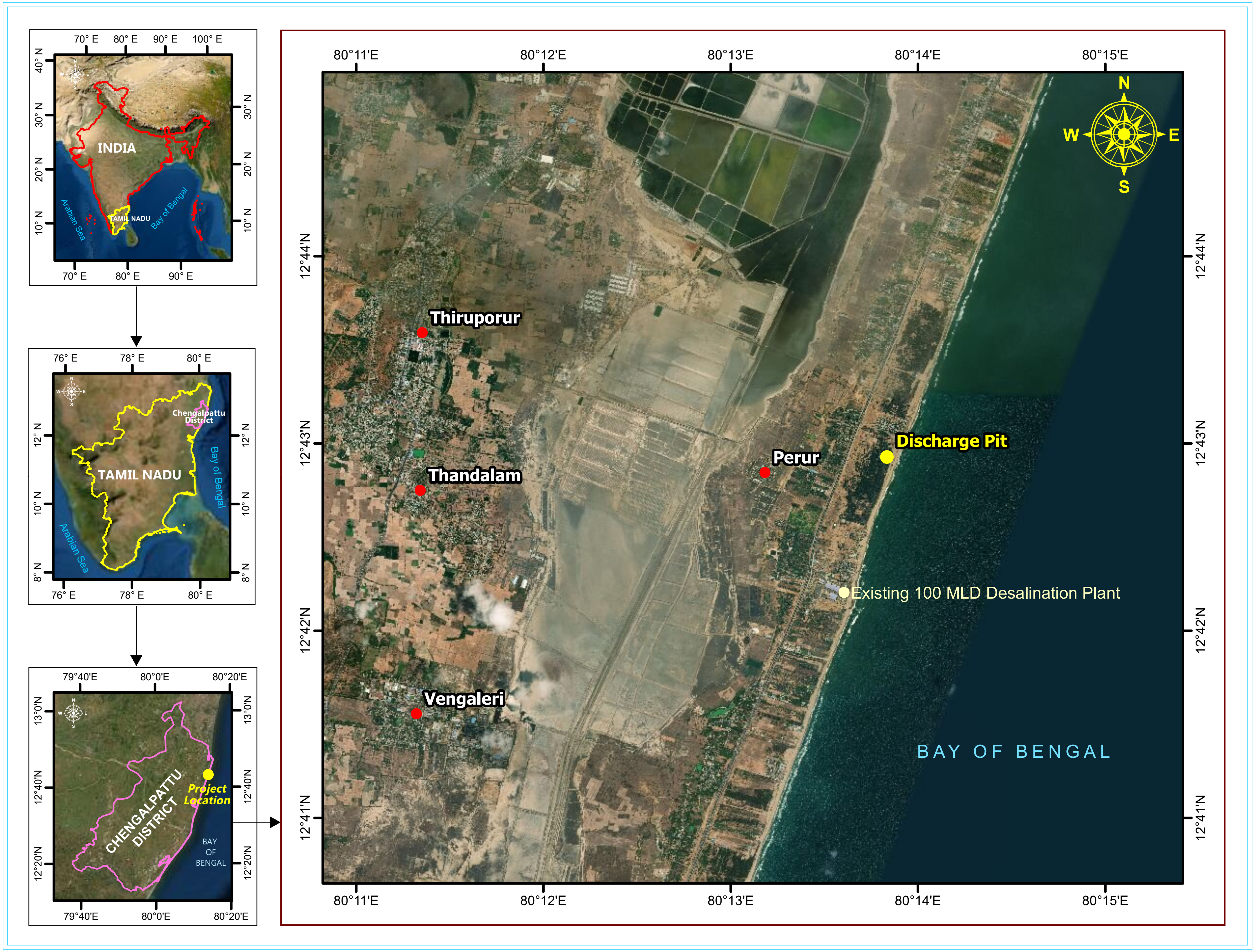


FIG. 1.1. LOCATION MAP

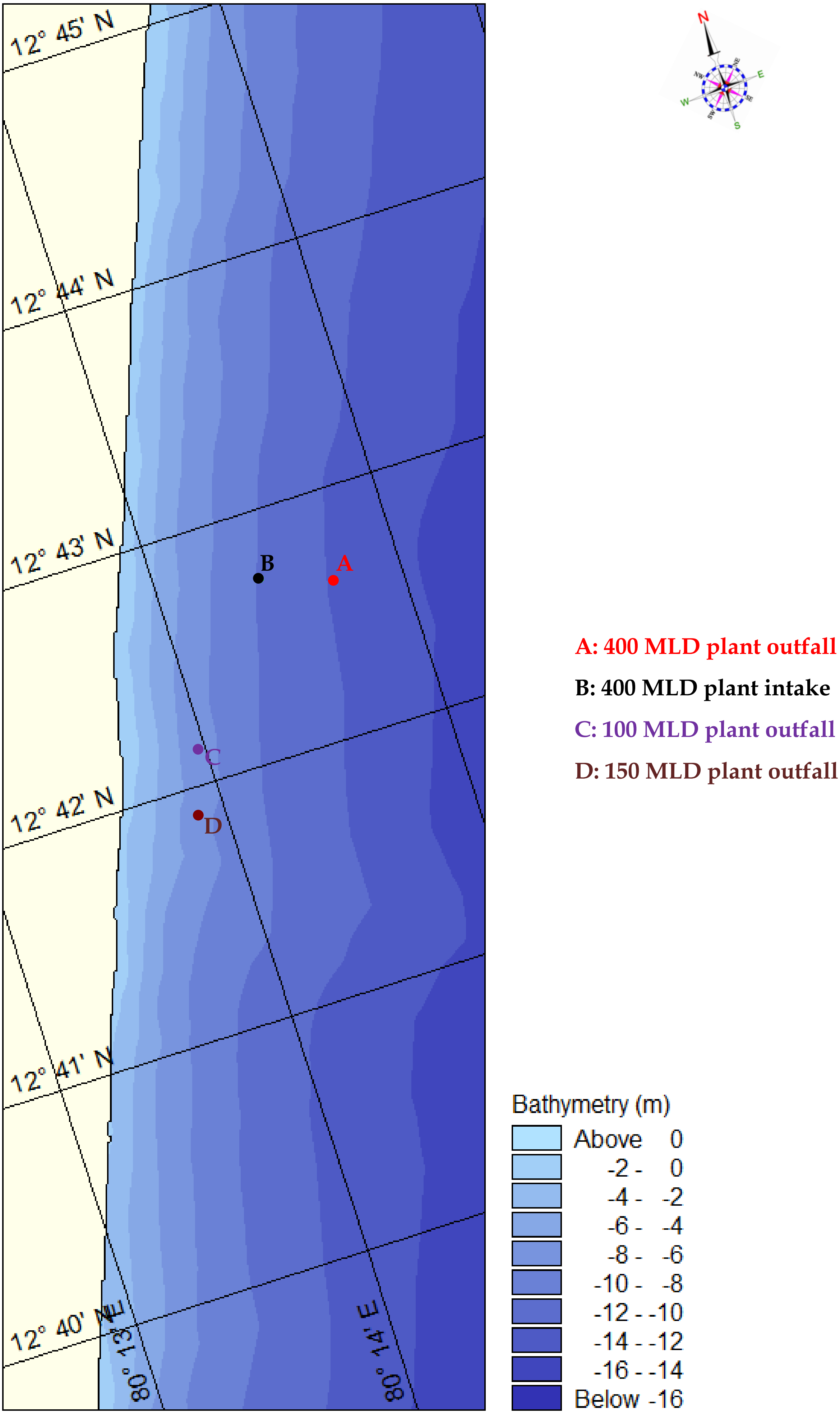


FIG. 4.1. BATHYMETRY

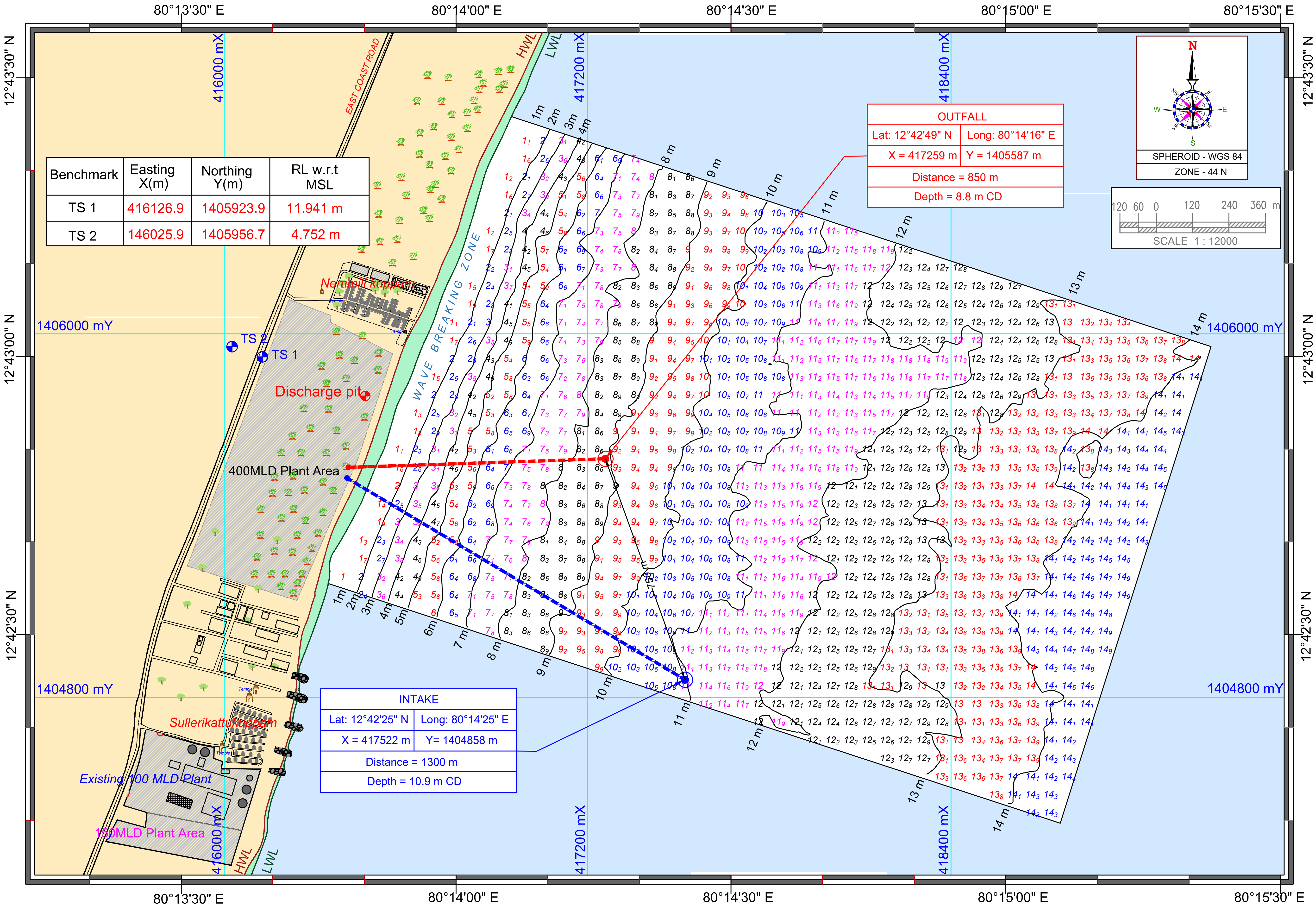
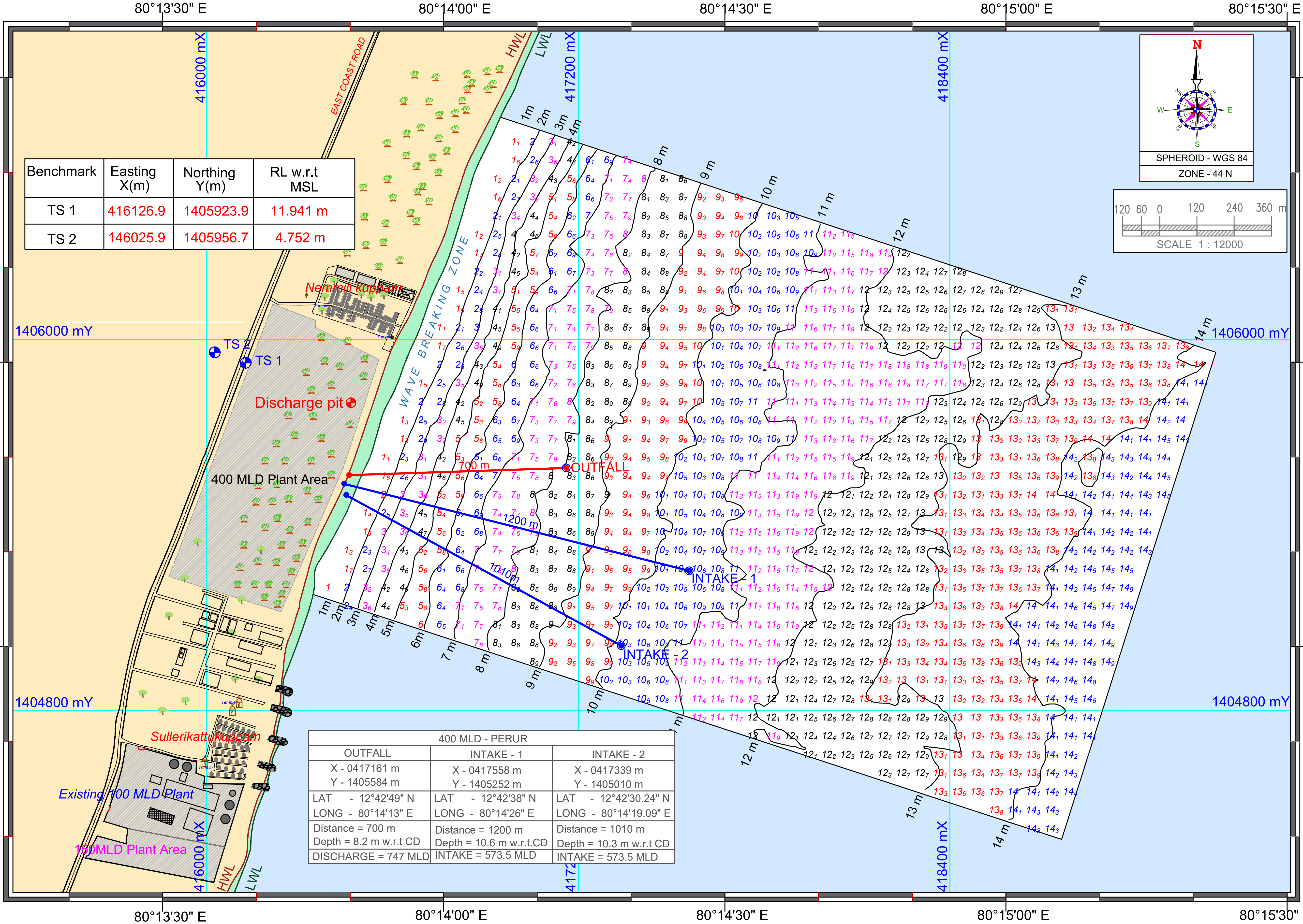


FIG. 5.3. LOCATIONS OF BRINE REJECT DISCHARGE - CASE III (SUGGESTED BY INDOMER)



Benchmark	Easting X(m)	Northing Y(m)	RL w.r.t MSL
TS 1	416126.9	1405923.9	11.941 m
TS 2	146025.9	1405956.7	4.752 m

400 MLD - PERUR		
OUTFALL	INTAKE - 1	INTAKE - 2
X - 0417161 m Y - 1405584 m	X - 0417558 m Y - 1405252 m	X - 0417339 m Y - 1405010 m
LAT - 12°42'49" N LONG - 80°14'13" E	LAT - 12°42'38" N LONG - 80°14'26" E	LAT - 12°42'30.24" N LONG - 80°14'19.09" E
Distance = 700 m Depth = 8.2 m w.r.t CD	Distance = 1200 m Depth = 10.6 m w.r.t.CD	Distance = 1010 m Depth = 10.3 m w.r.t CD
DISCHARGE = 747 MLD	INTAKE = 573.5 MLD	INTAKE = 573.5 MLD

FIG. 5.1. LOCATIONS OF BRINE REJECT DISCHARGE - CASE I (GIVEN IN DPR)

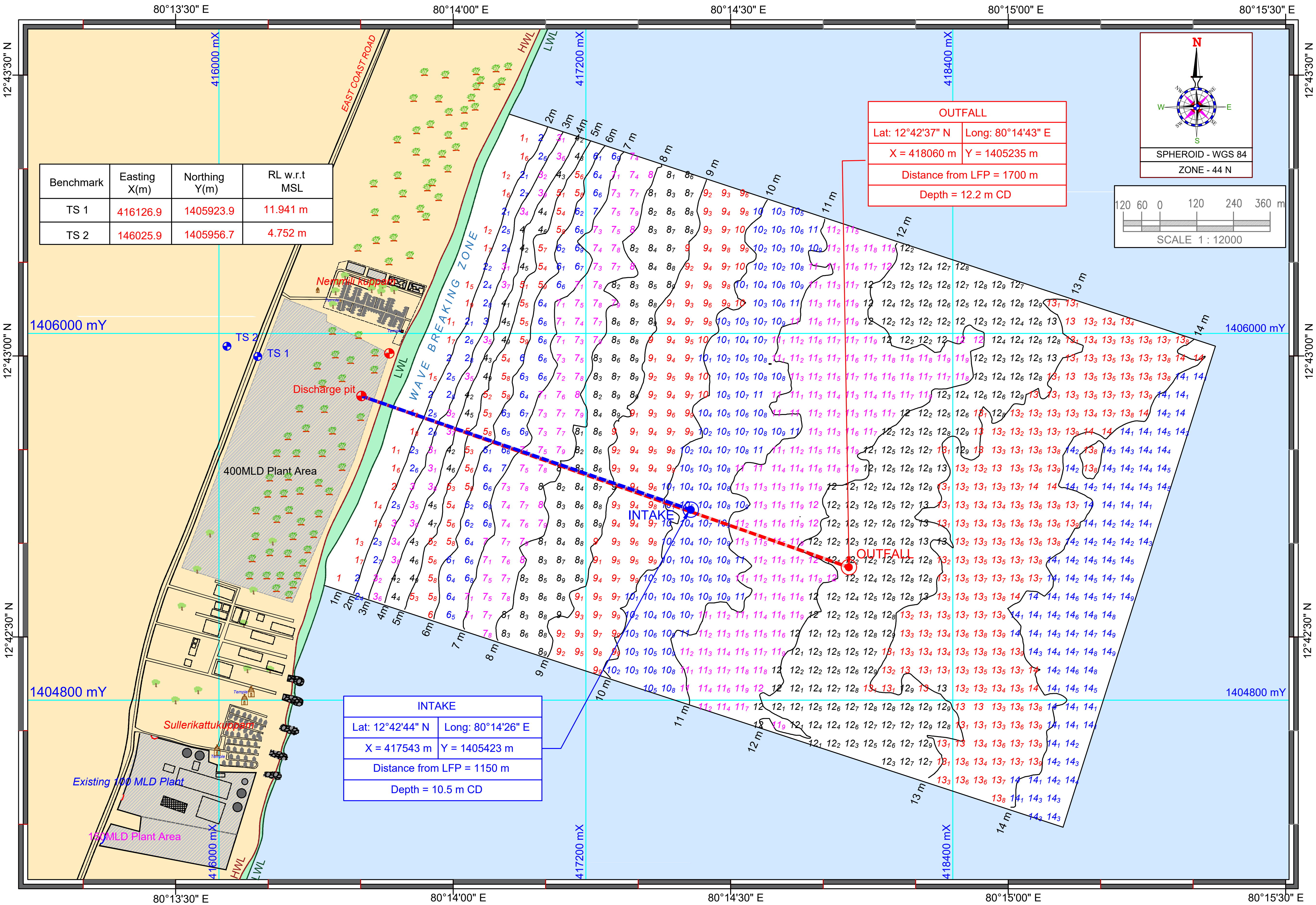


FIG.5.2. LOCATIONS OF BRINE REJECT DISCHARGE - CASE II (ADOPTED IN JICA STUDY)

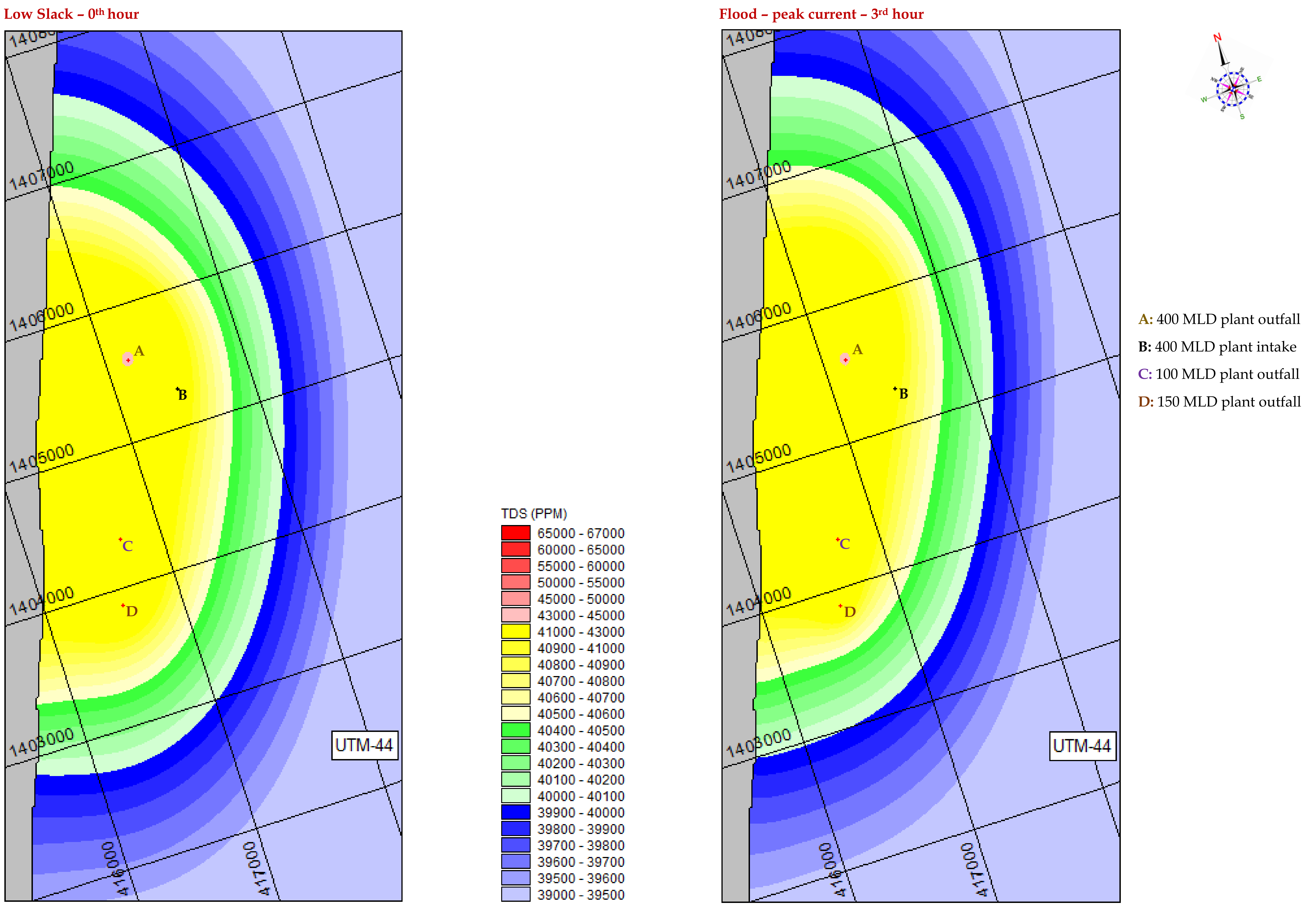


FIG. 6.1(A). SECONDARY DISPERSION – FAIR WEATHER - SPRING TIDE – CASE I (GIVEN IN DPR) – (TDS)

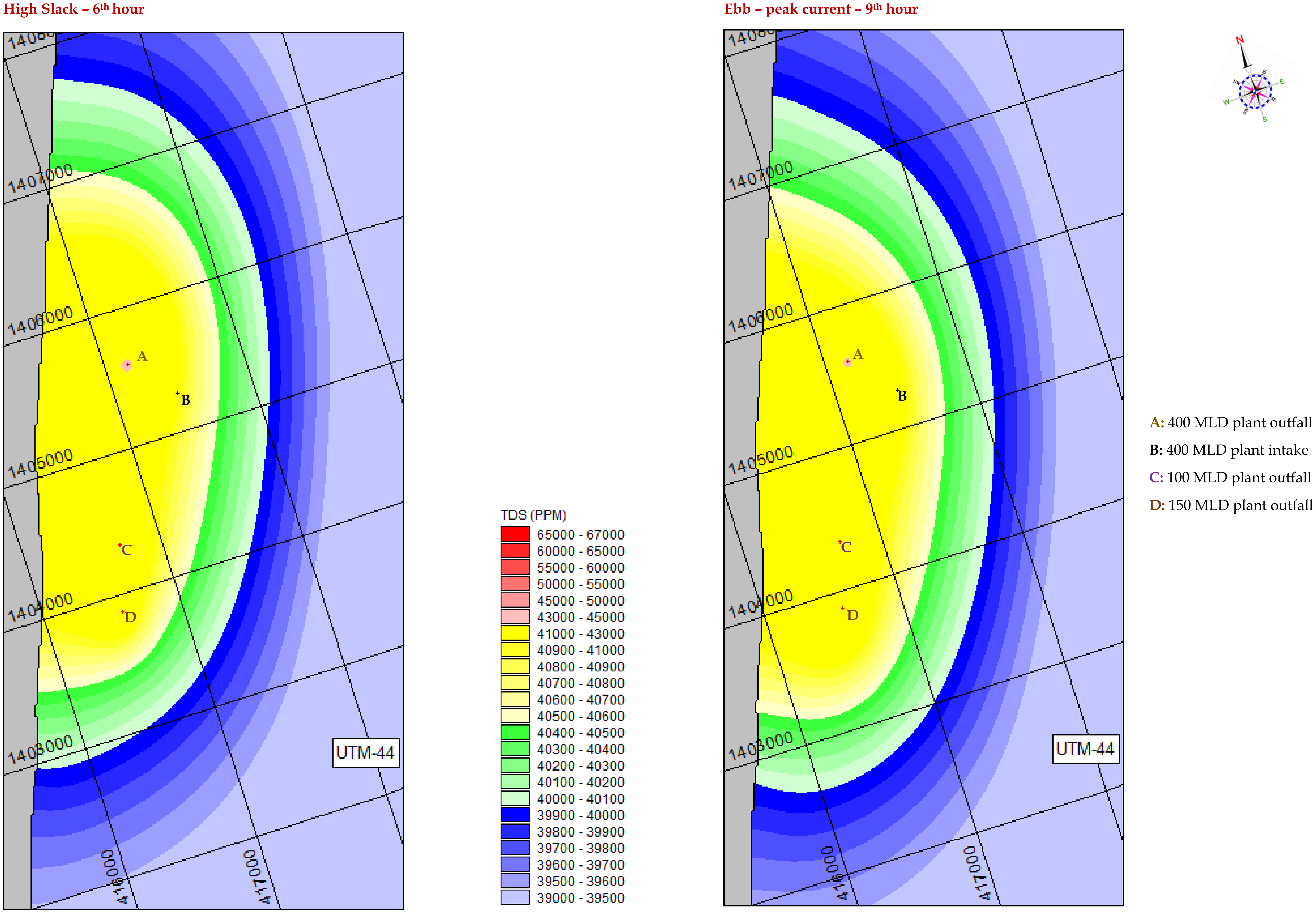


FIG. 6.1(B). SECONDARY DISPERSION – FAIR WEATHER - SPRING TIDE – CASE I (GIVEN IN DPR) – (TDS)

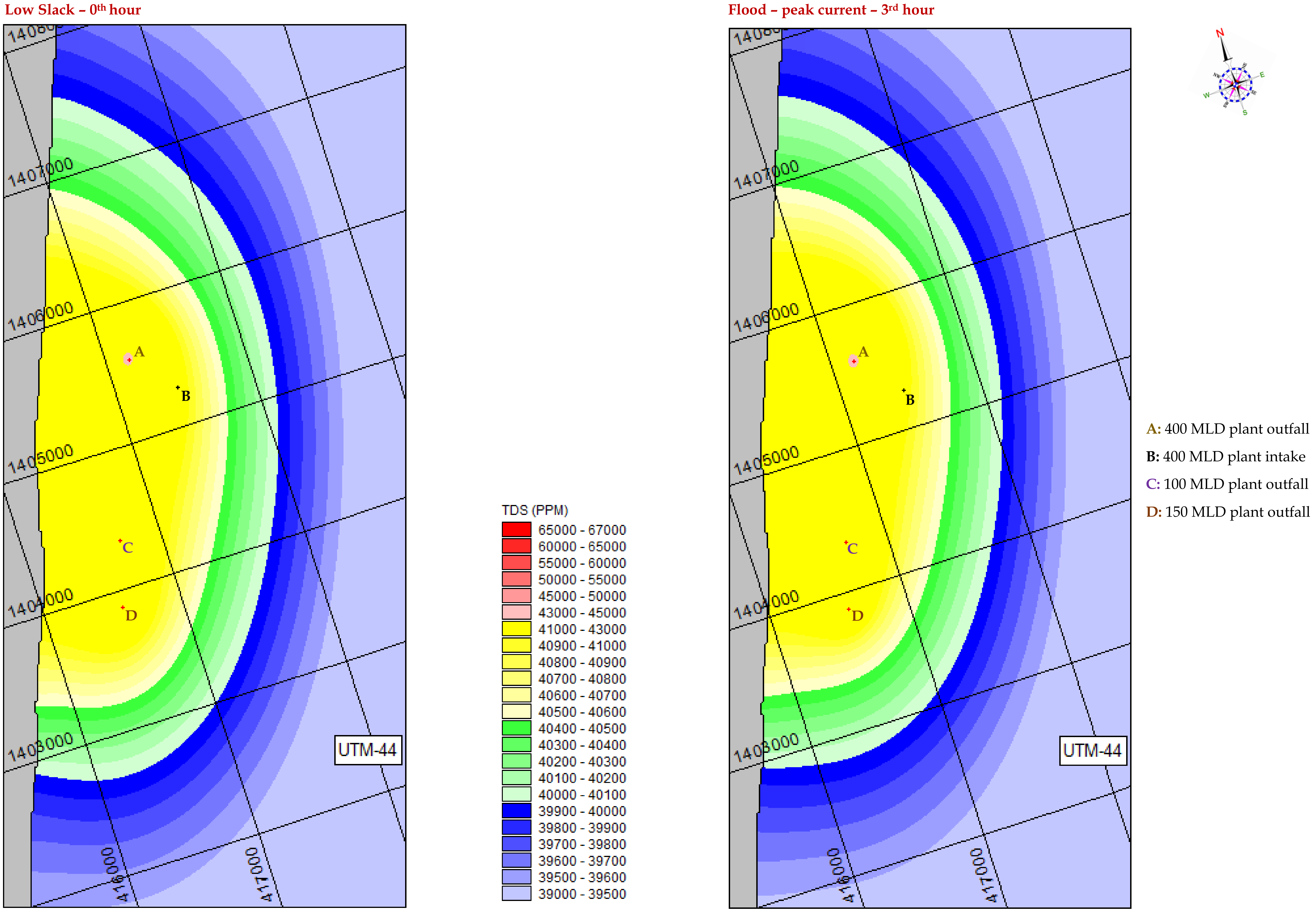


FIG. 6.2(A). SECONDARY DISPERSION – FAIR WEATHER - NEAP TIDE – CASE I (GIVEN IN DPR) – (TDS)

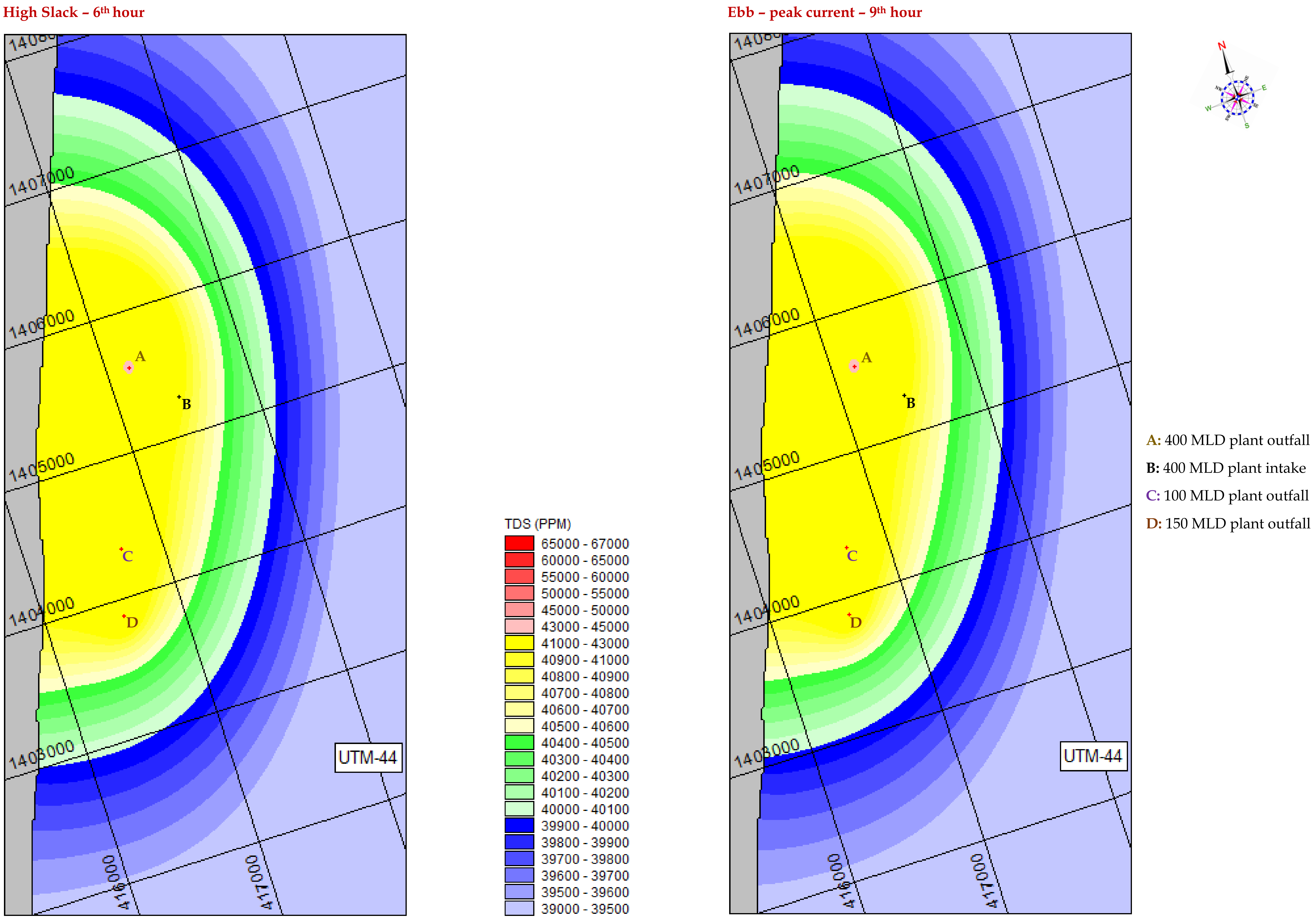


FIG. 6.2(B). SECONDARY DISPERSION – FAIR WEATHER - NEAP TIDE – CASE I (GIVEN IN DPR) – (TDS)

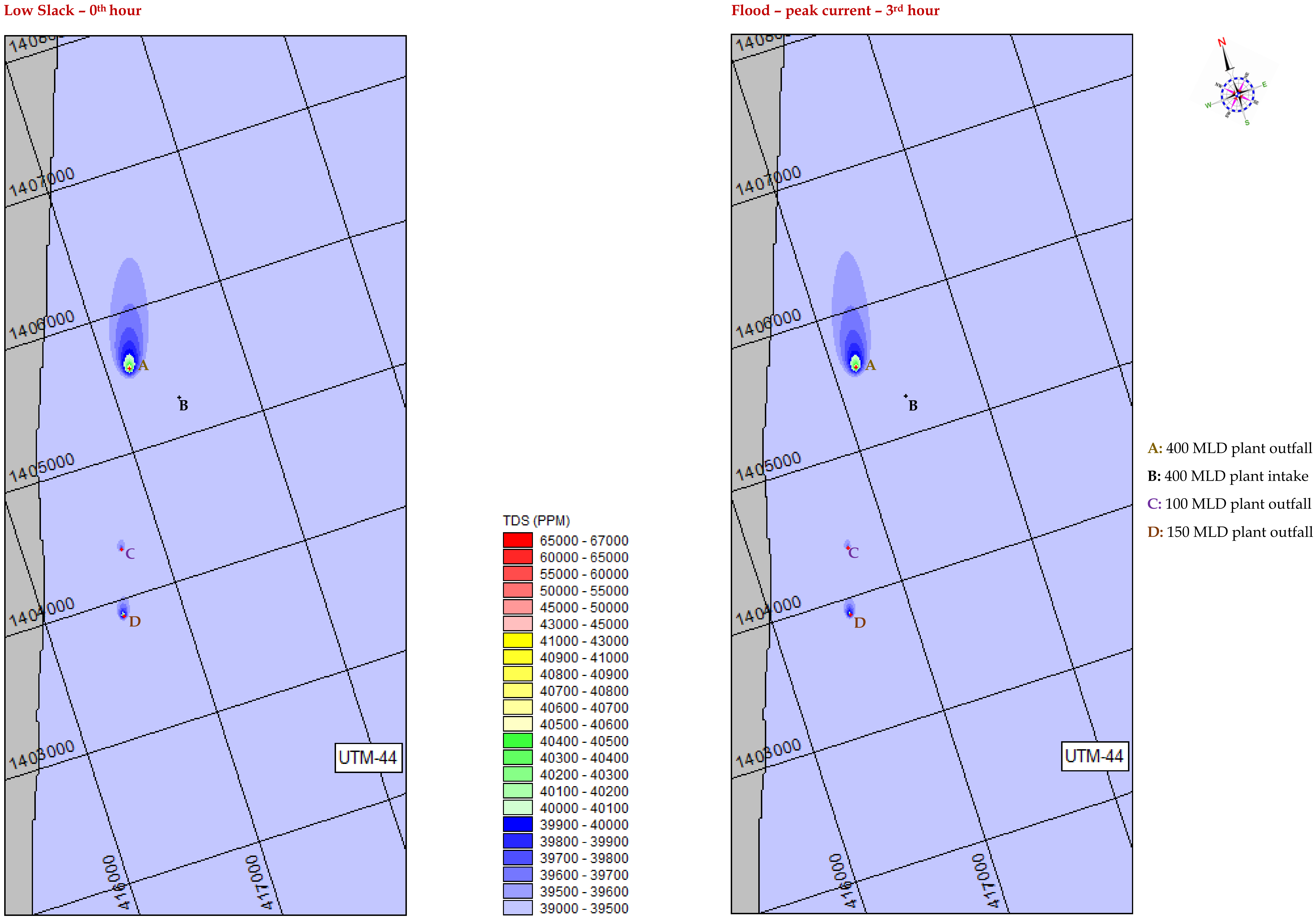


FIG. 6.3(A). SECONDARY DISPERSION – SW MONSOON - SPRING TIDE – CASE I (GIVEN IN DPR) – (TDS)

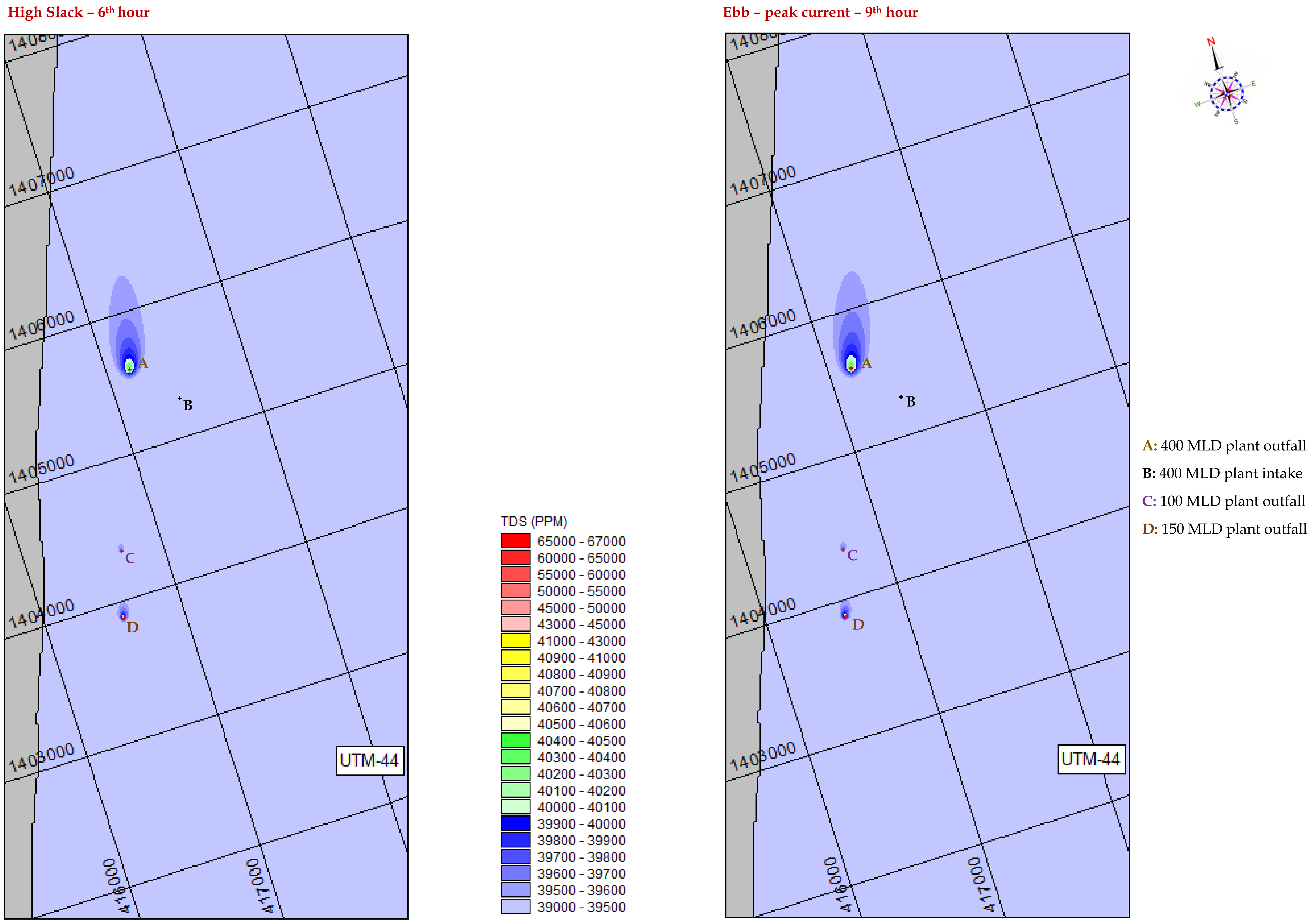


FIG. 6.3(B). SECONDARY DISPERSION – SW MONSOON - SPRING TIDE – CASE I (GIVEN IN DPR) – (TDS)

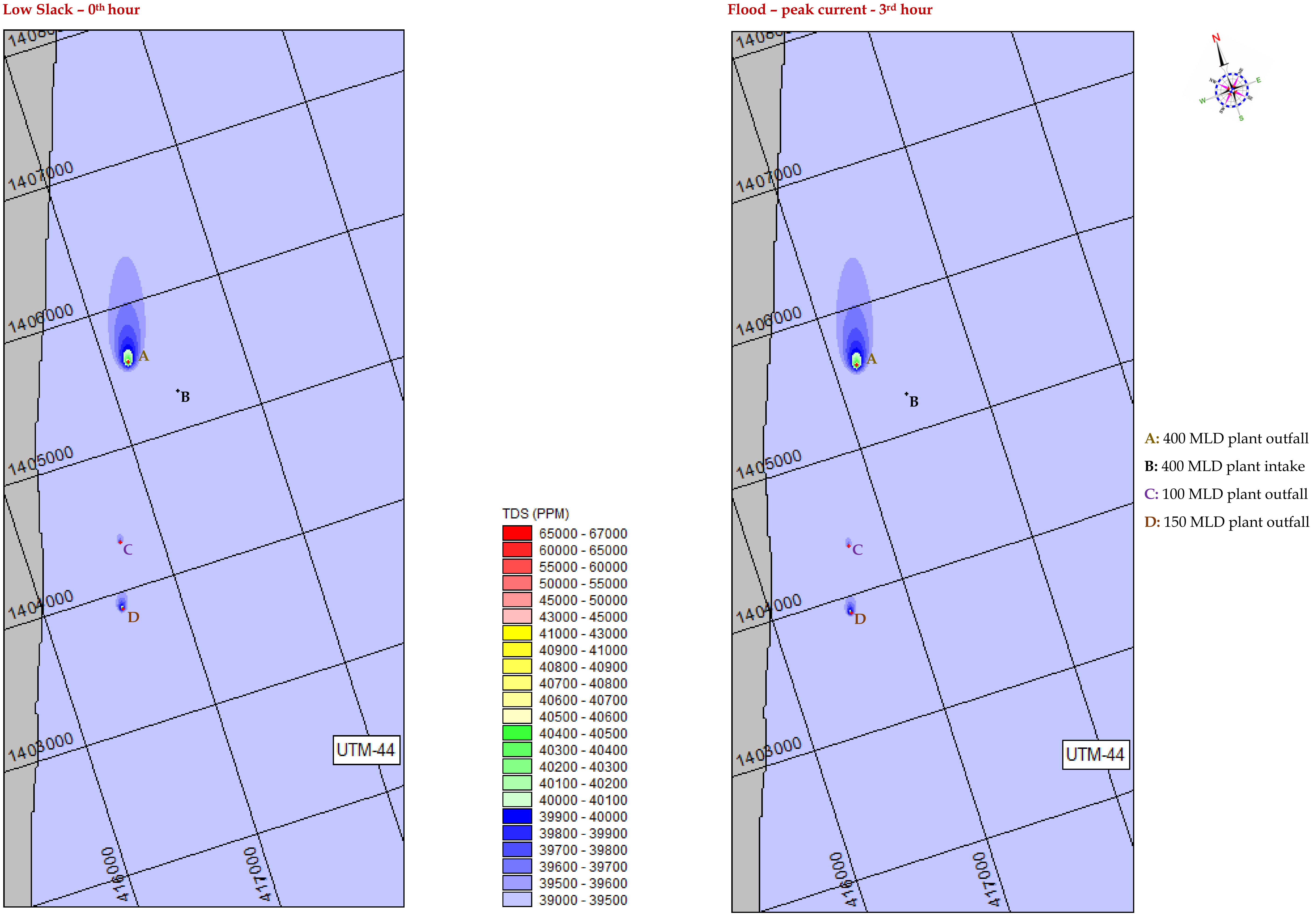


FIG. 6.4(A). SECONDARY DISPERSION – SW MONSOON - NEAP TIDE – CASE I (GIVEN IN DPR) – (TDS)

High Slack – 6th hour

Ebb – peak current - 9th hour

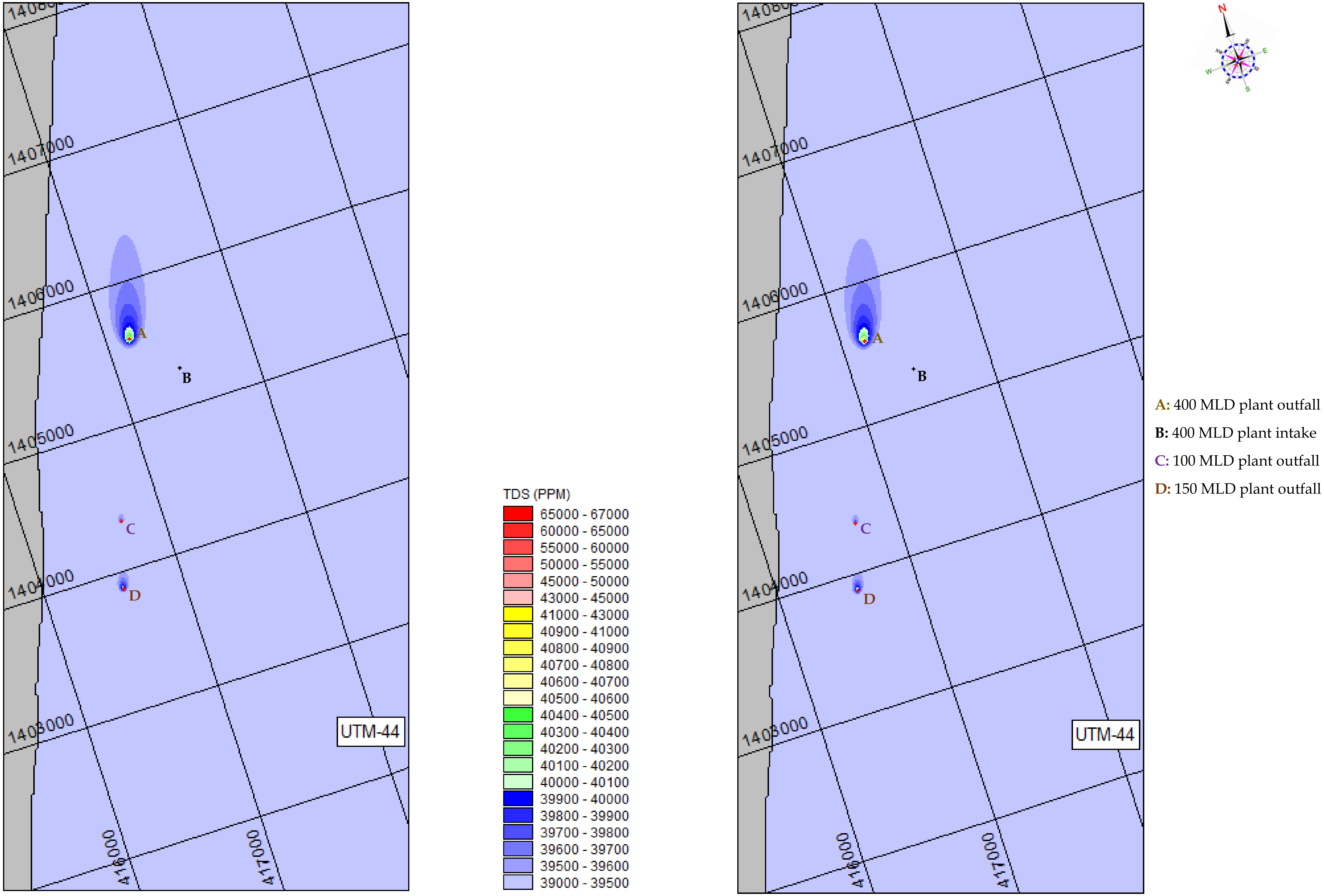


FIG. 6.4(B). SECONDARY DISPERSION – SW MONSOON - NEAP TIDE – CASE I (GIVEN IN DPR) – (TDS)

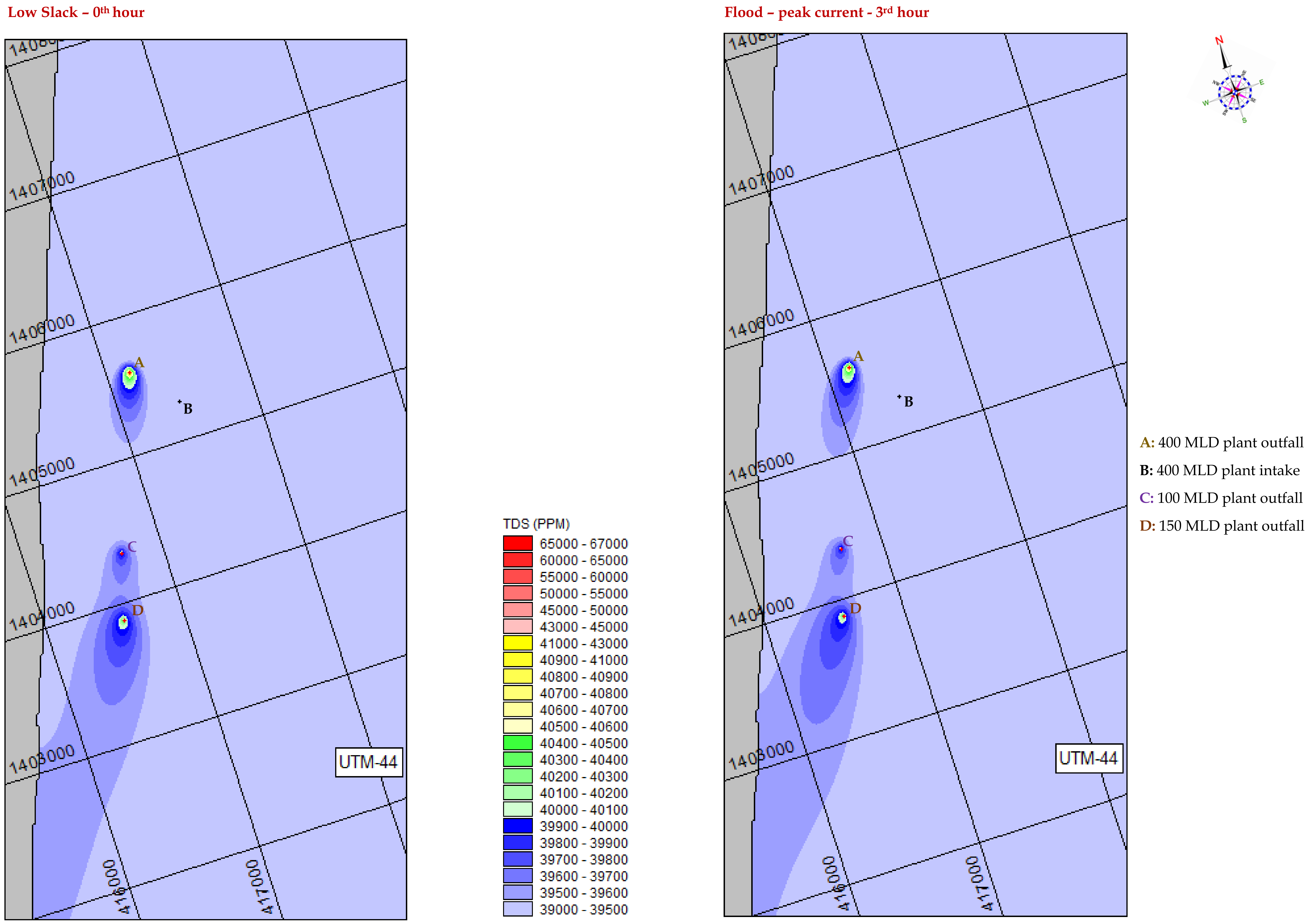


FIG. 6.5(A). SECONDARY DISPERSION – NE MONSOON - SPRING TIDE – CASE I (GIVEN IN DPR) – (TDS)

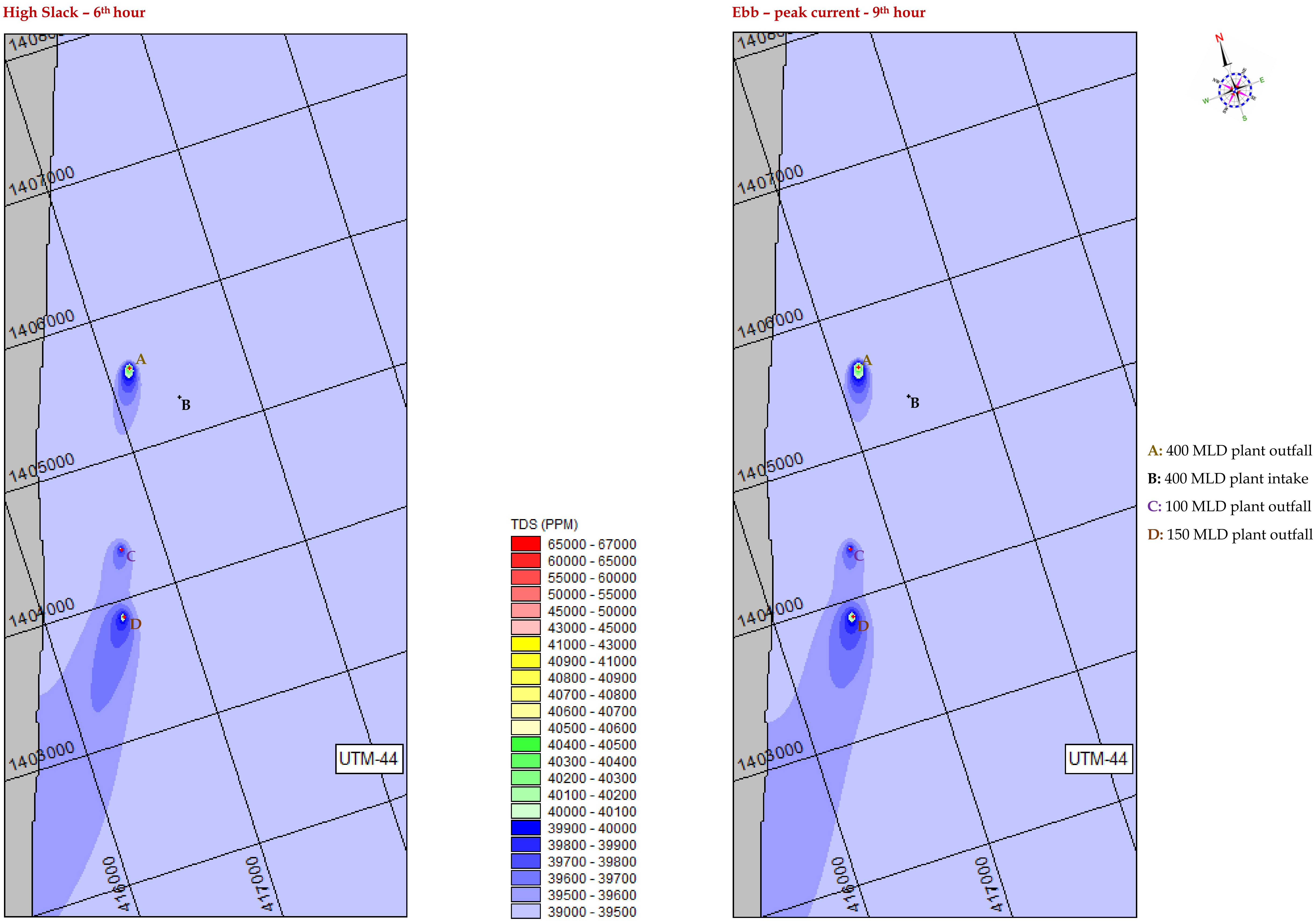


FIG. 6.5(B). SECONDARY DISPERSION – NE MONSOON - SPRING TIDE – CASE I (GIVEN IN DPR) – (TDS)

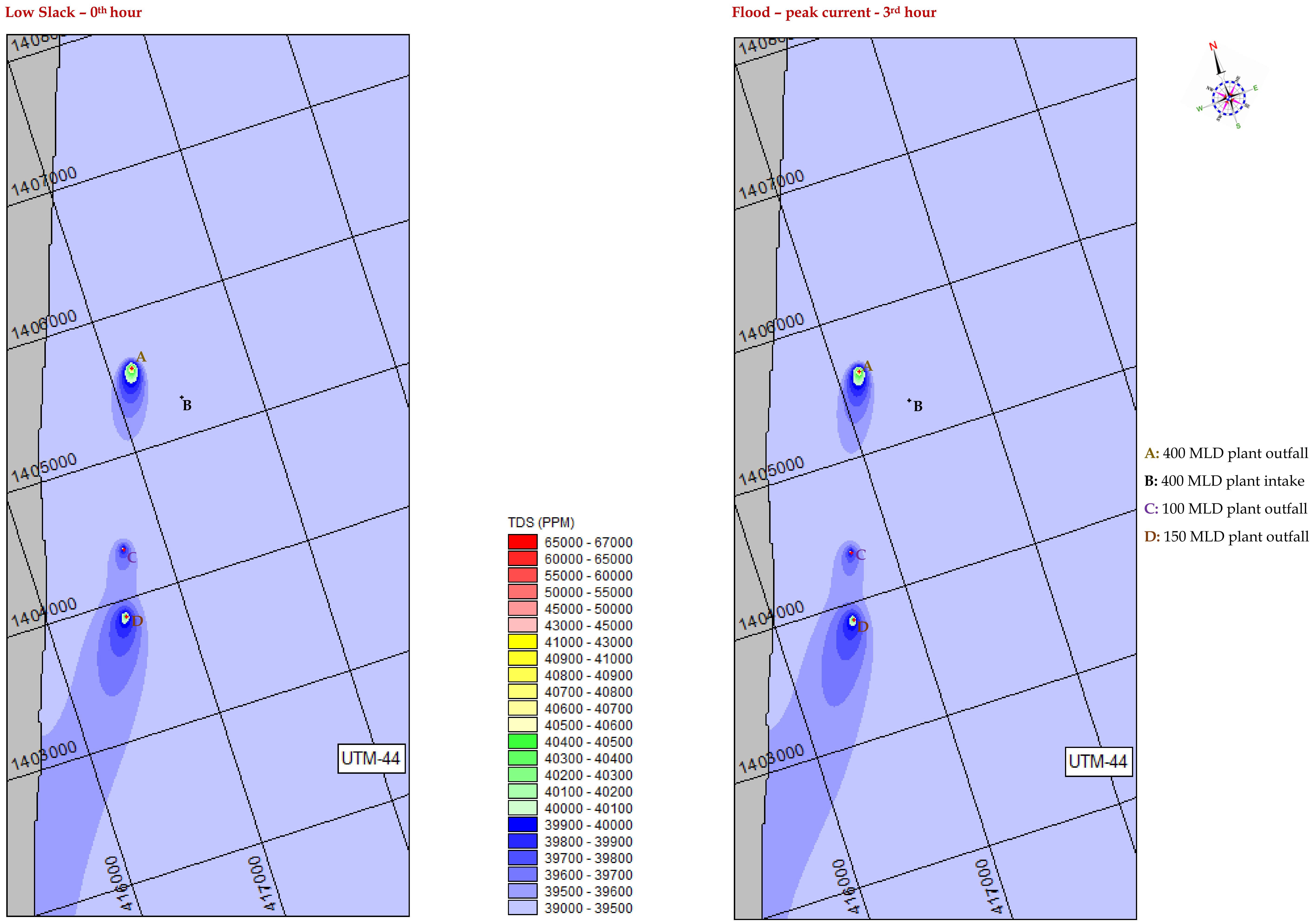


FIG. 6.6(A). SECONDARY DISPERSION – NE MONSOON - NEAP TIDE – CASE I (GIVEN IN DPR) – (TDS)

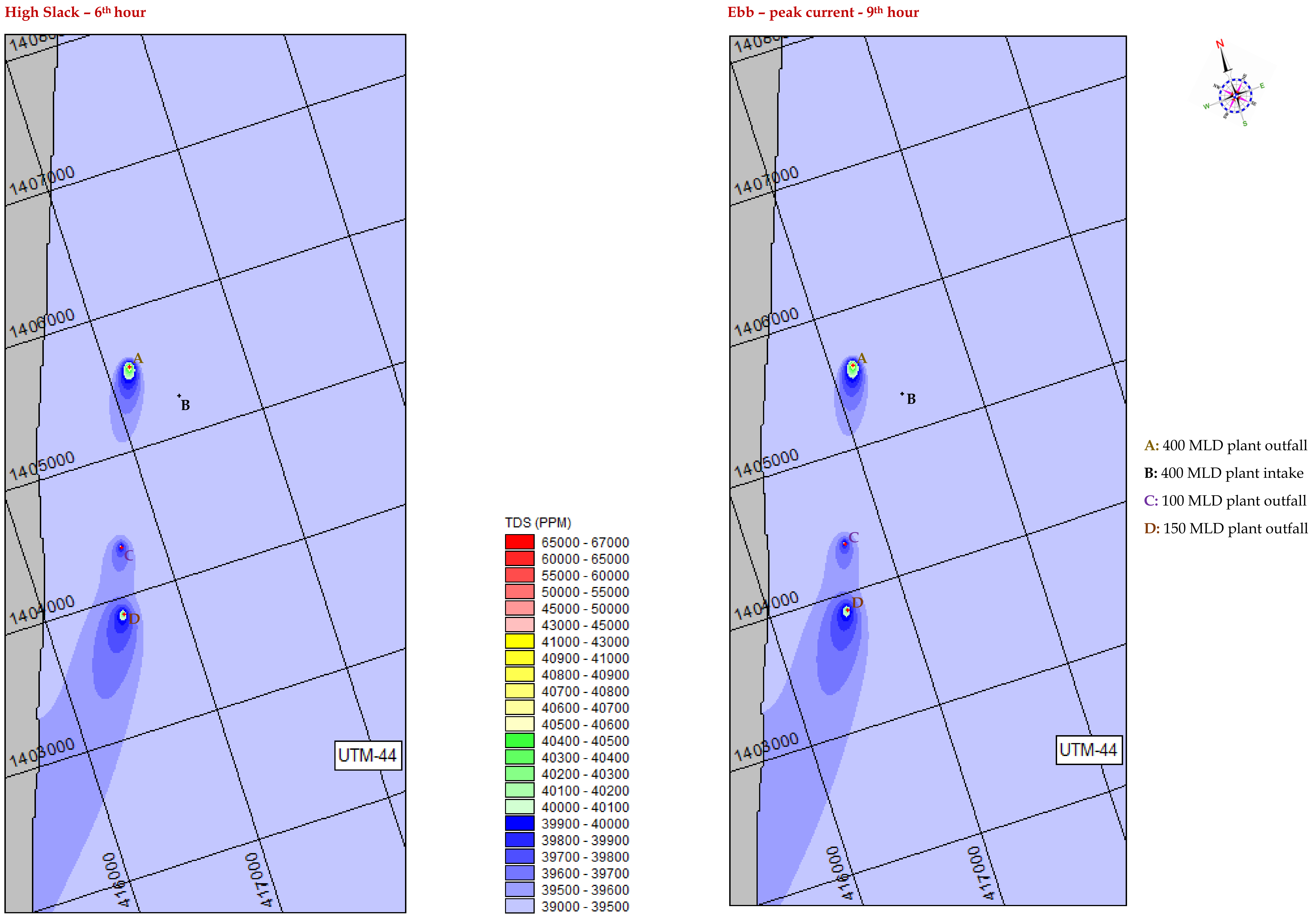


FIG. 6.6(B). SECONDARY DISPERSION – NE MONSOON - NEAP TIDE – CASE I (GIVEN IN DPR) – (TDS)

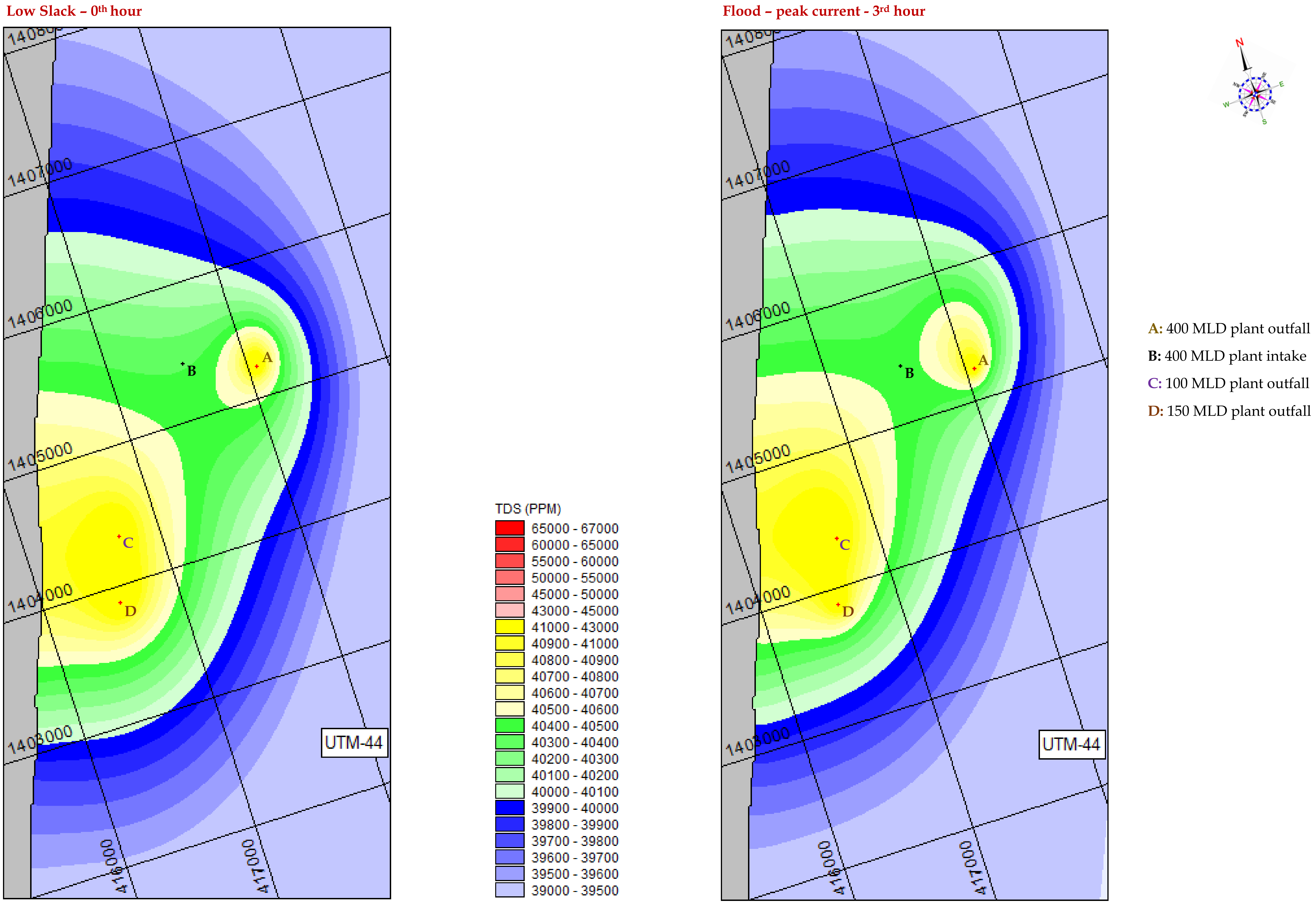


FIG. 6.7(A). SECONDARY DISPERSION – FAIR WEATHER - SPRING TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

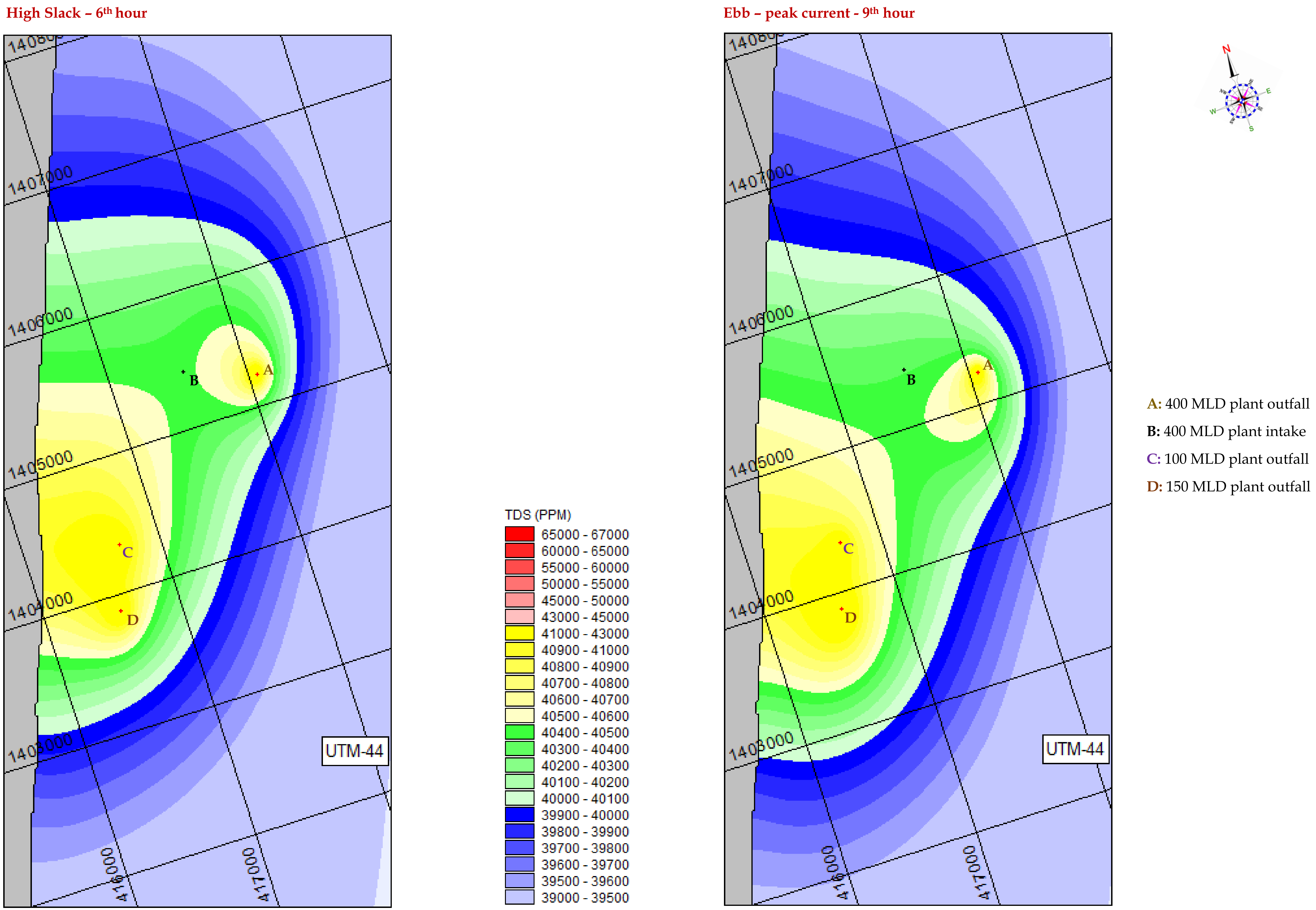


FIG. 6.7(B). SECONDARY DISPERSION – FAIR WEATHER - SPRING TIDE – CASE II (ADOPTED IN JICA STUDY)– (TDS)

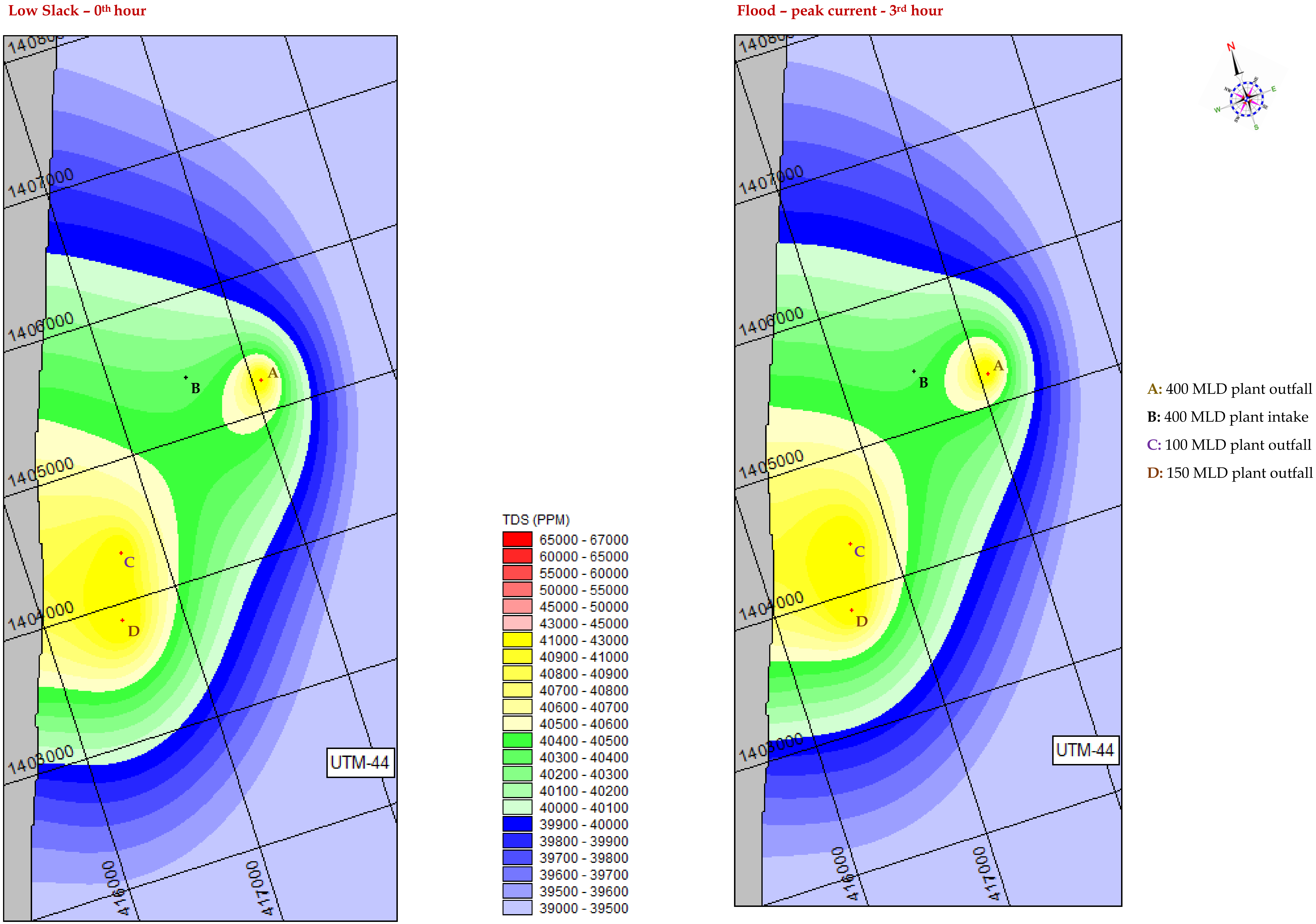


FIG. 6.8(A). SECONDARY DISPERSION – FAIR WEATHER - NEAP TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

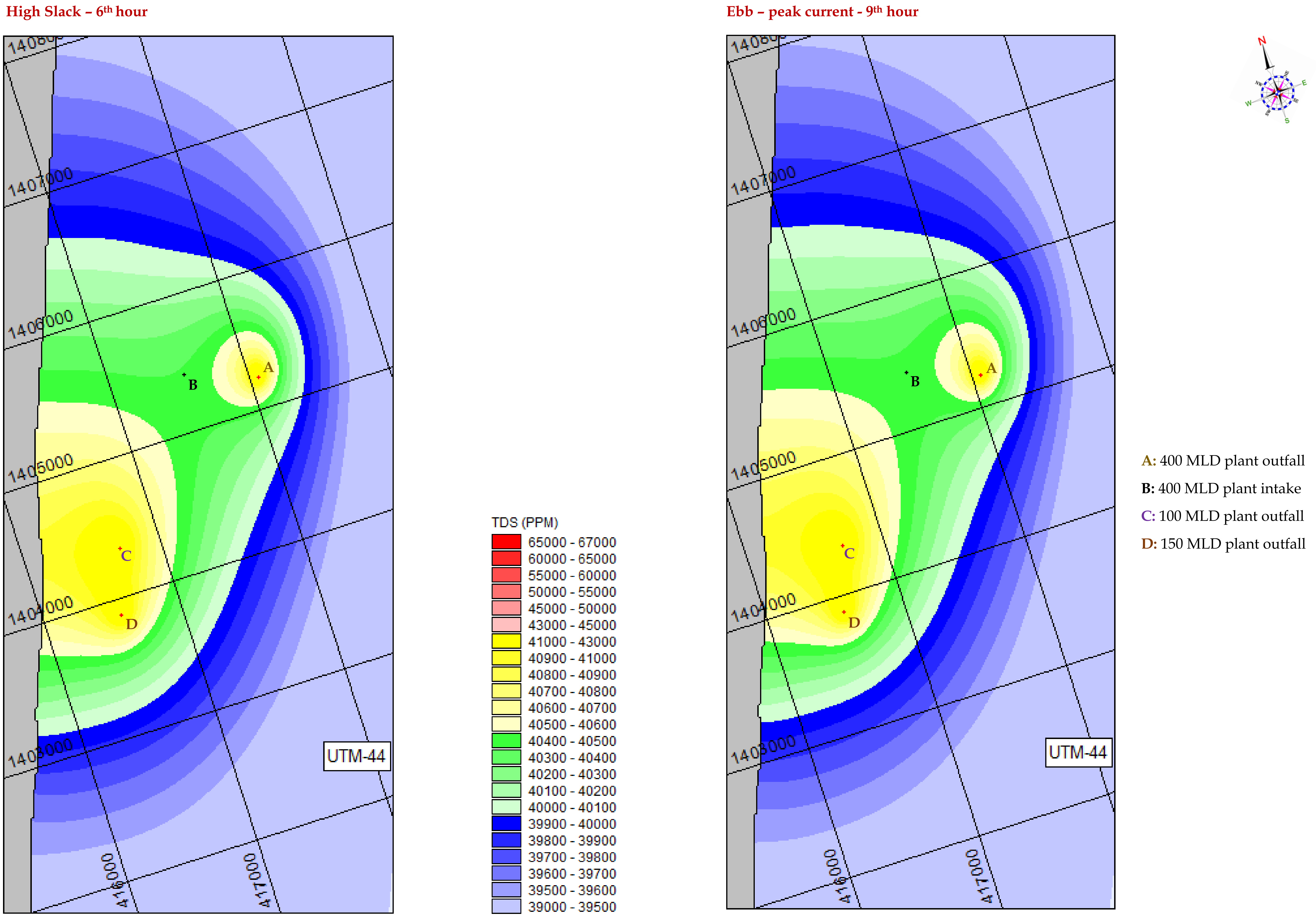


FIG. 6.8(B). SECONDARY DISPERSION – FAIR WEATHER - NEAP TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

Low Slack – 0th hour **Flood – peak current - 3rd hour**

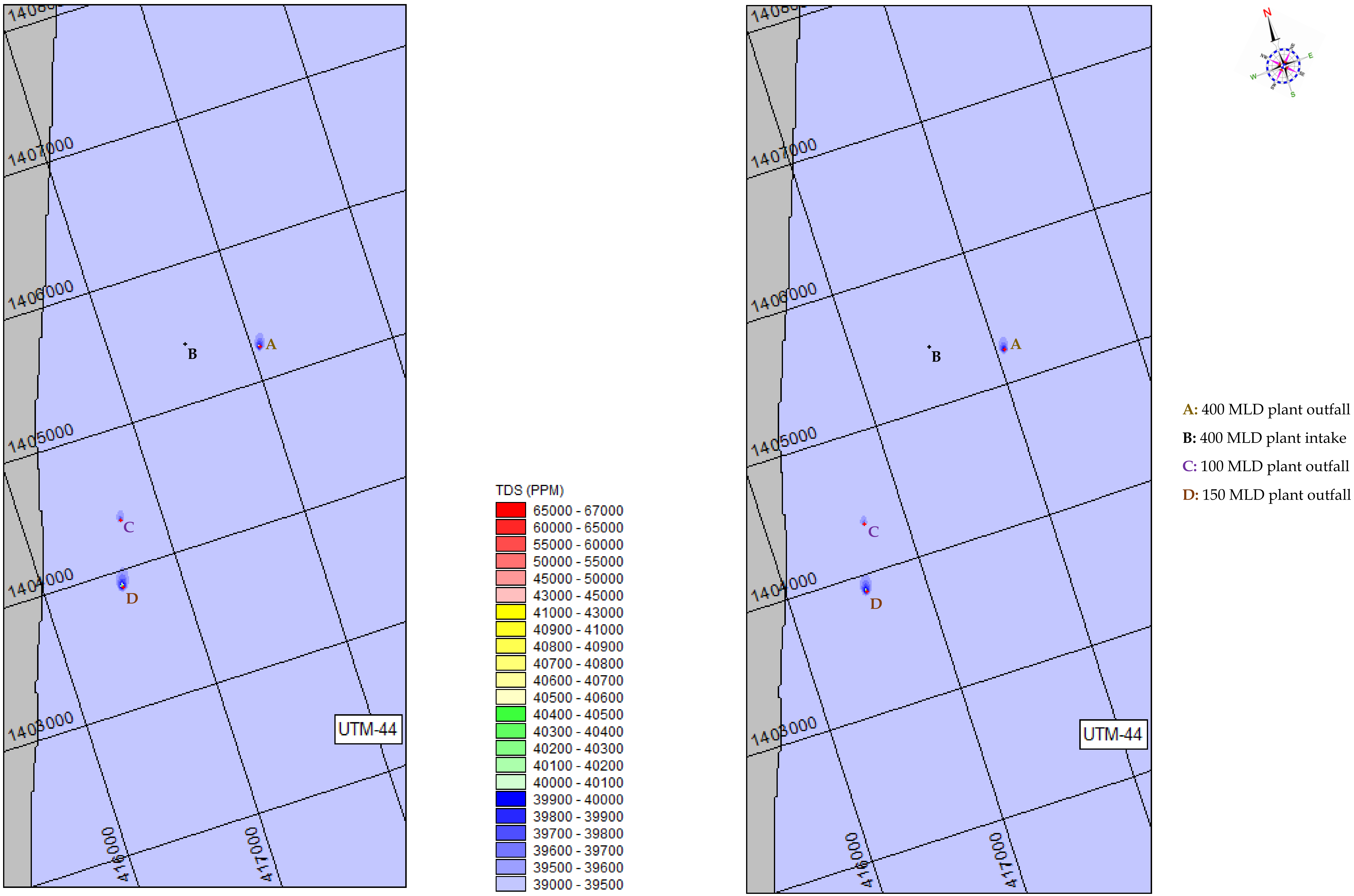


FIG. 6.9(A). SECONDARY DISPERSION – SW MONSOON - SPRING TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

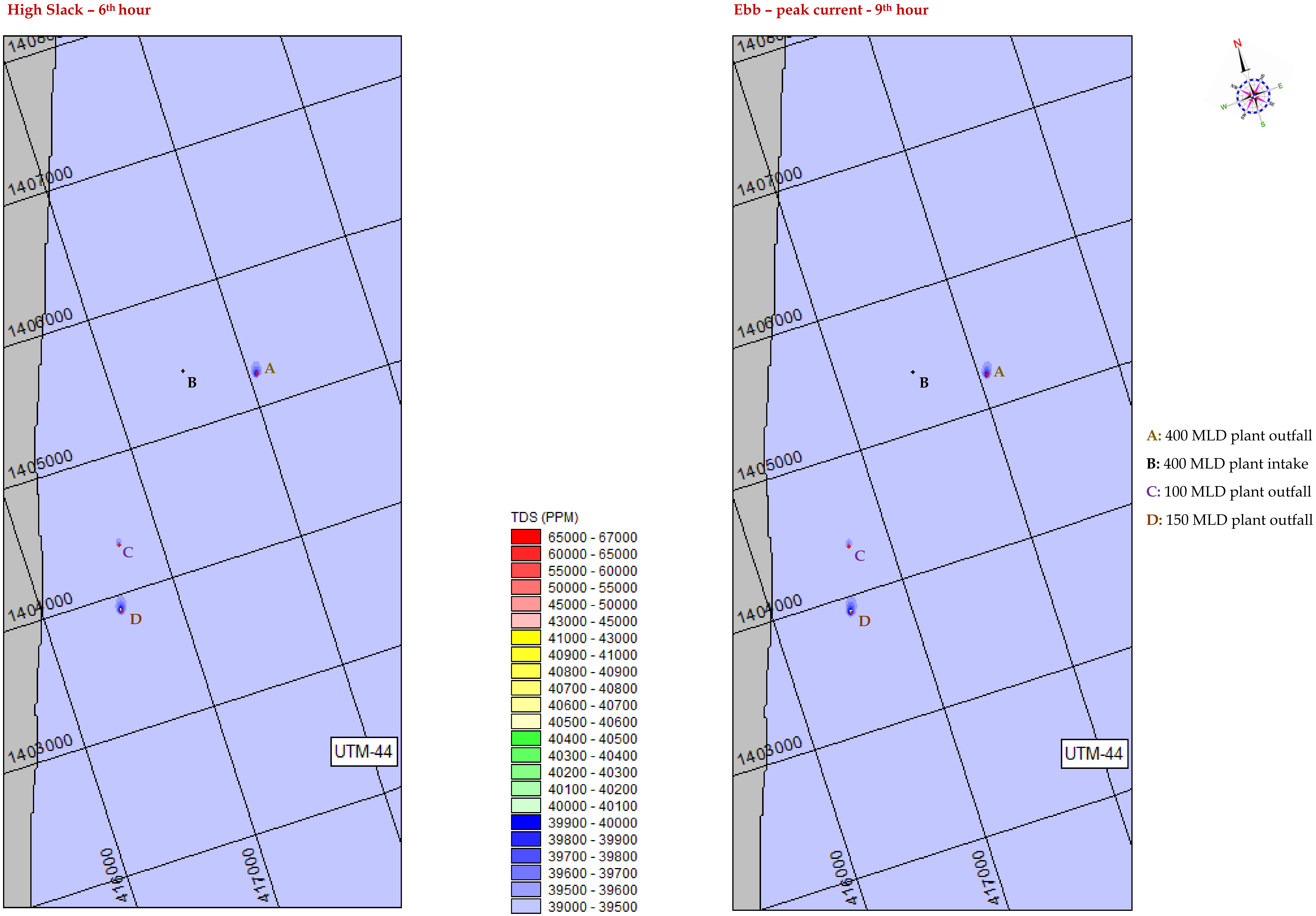


FIG. 6.9(B). SECONDARY DISPERSION – SW MONSOON - SPRING TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

Low Slack – 0th hour **Flood – peak current - 3rd hour**

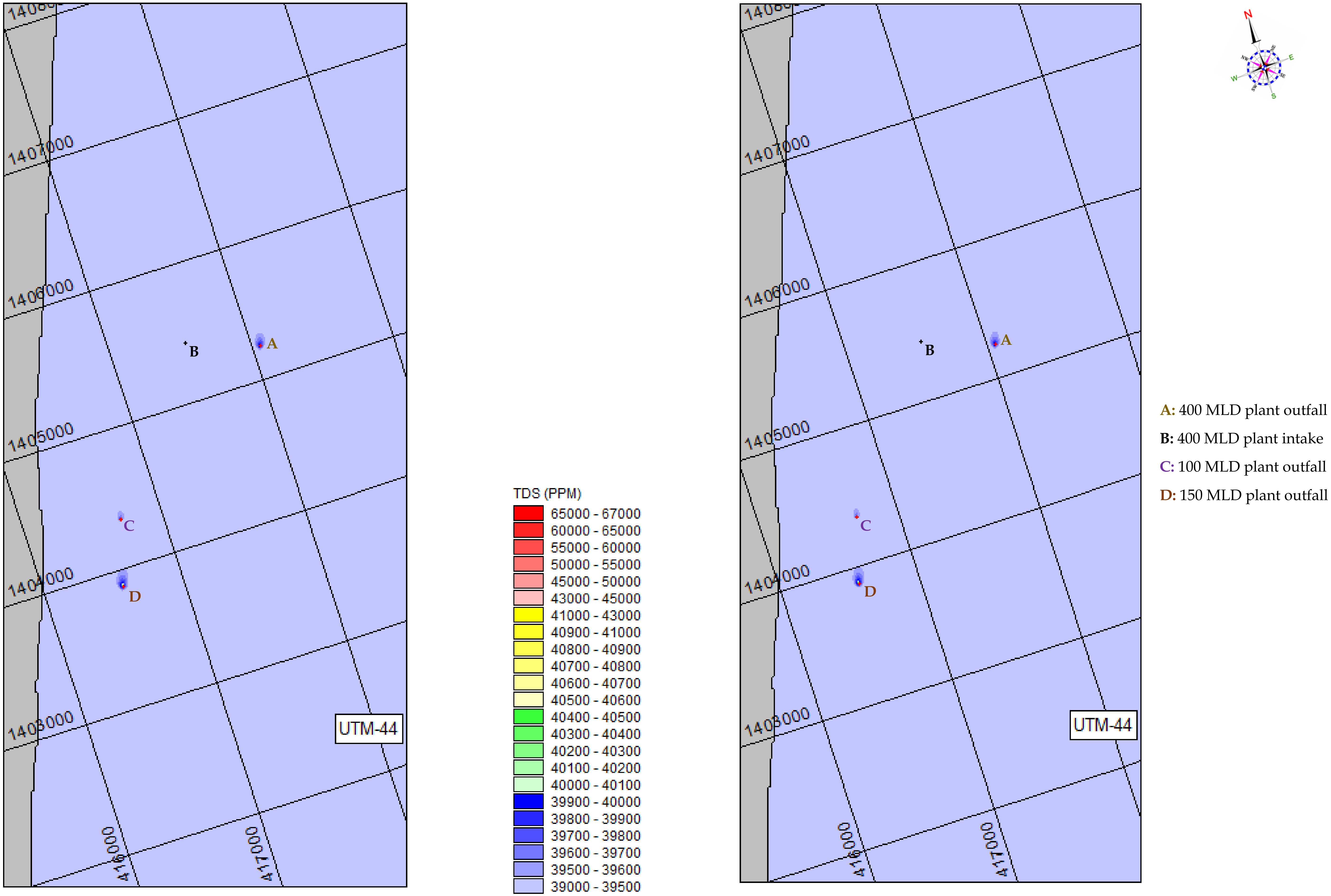


FIG. 6.10(A). SECONDARY DISPERSION – SW MONSOON - NEAP TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

High Slack – 6th hour **Ebb – peak current - 9th hour**

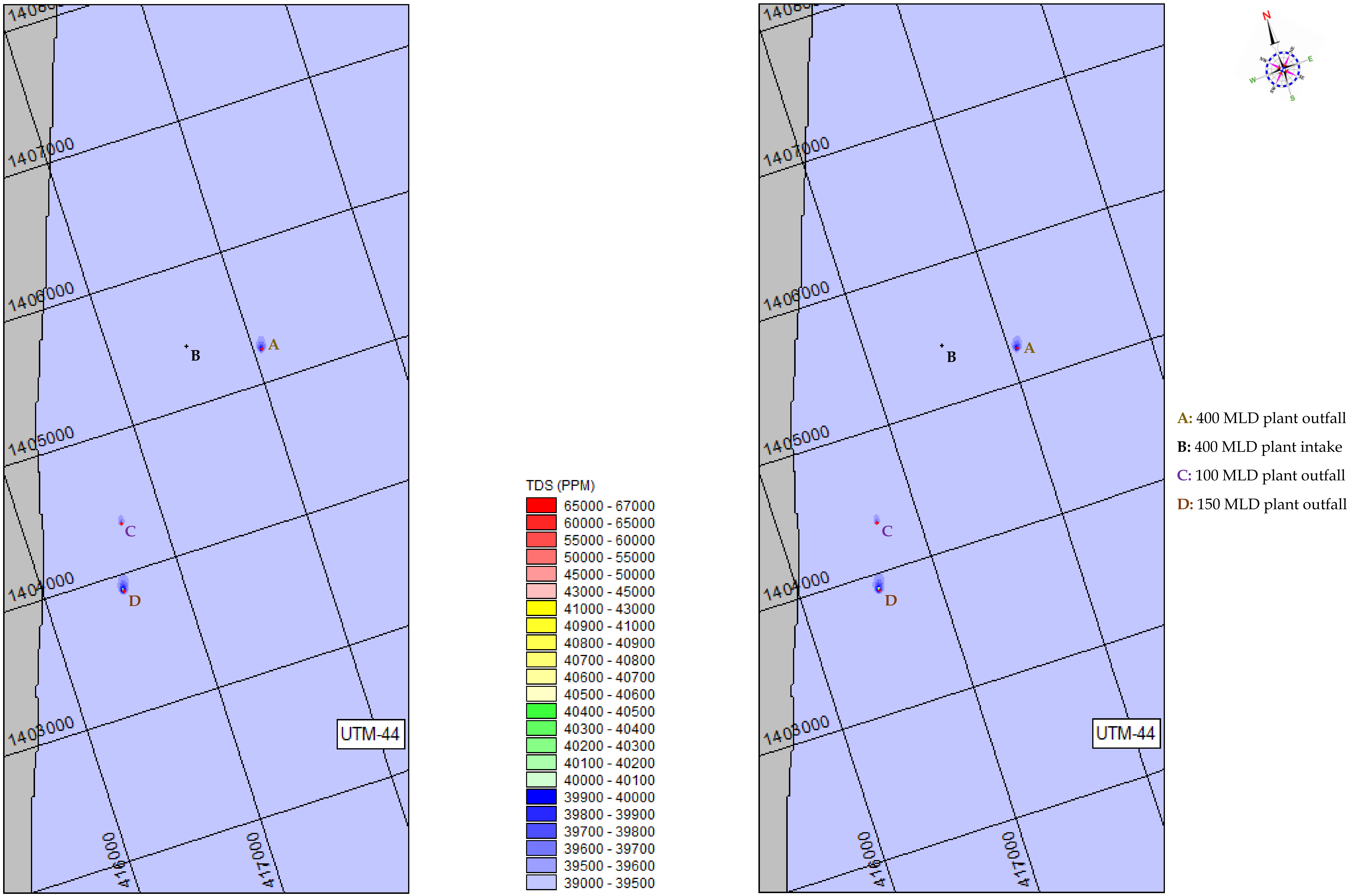


FIG. 6.10(B). SECONDARY DISPERSION – SW MONSOON - NEAP TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

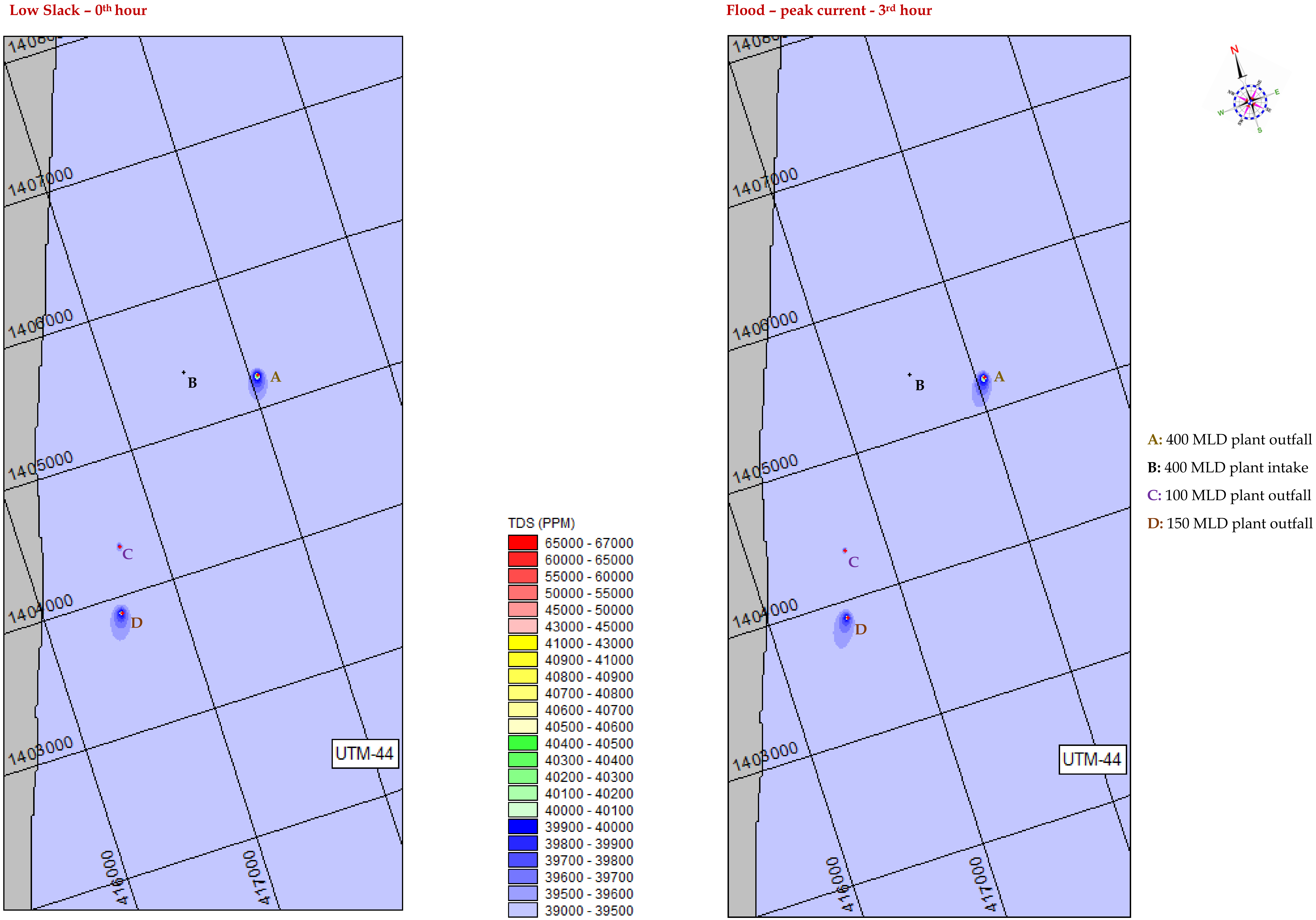


FIG. 6.11(A). SECONDARY DISPERSION – NE MONSOON - SPRING TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

High Slack – 6th hour

Ebb – peak current - 9th hour

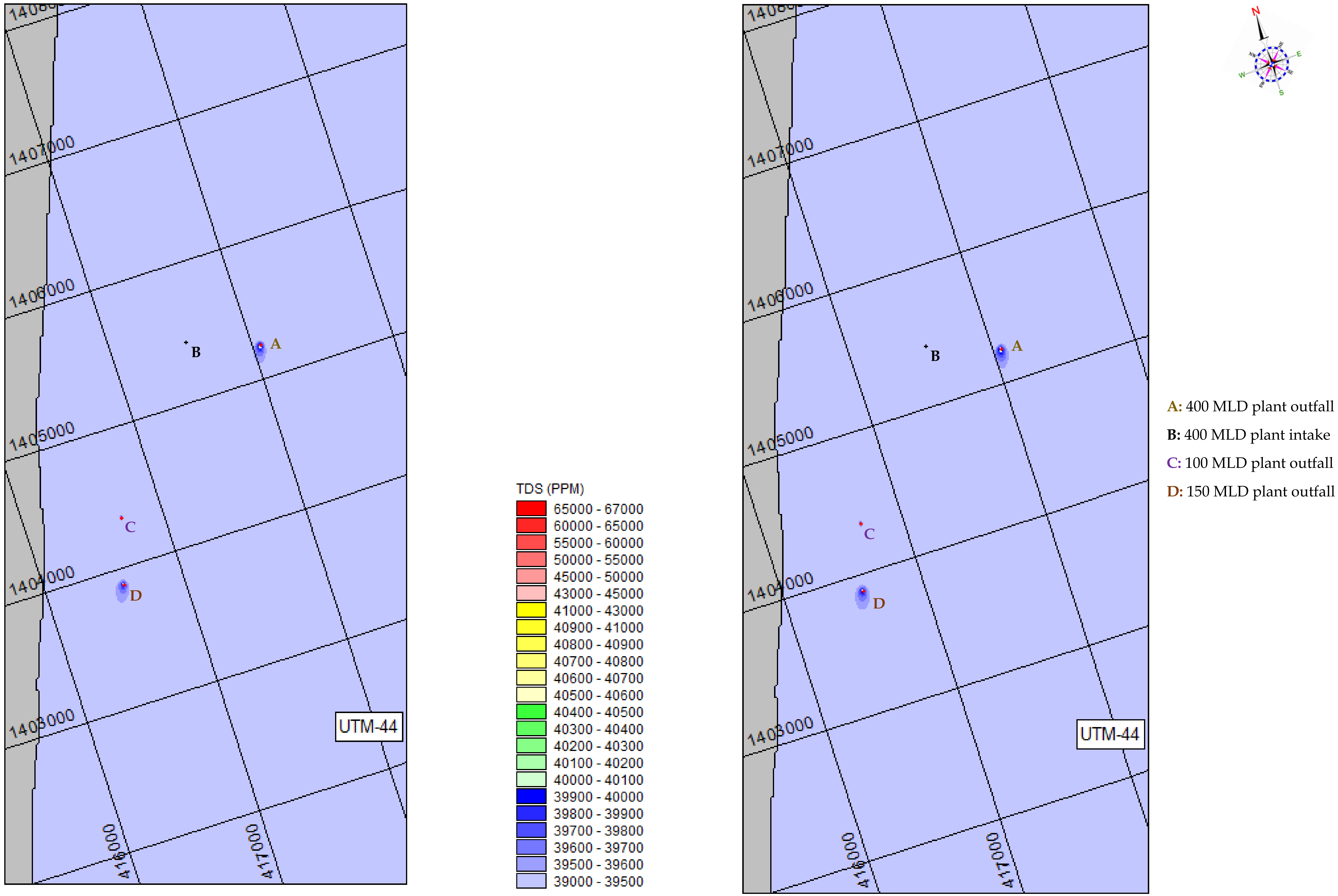


FIG. 6.11(B). SECONDARY DISPERSION – NE MONSOON - SPRING TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

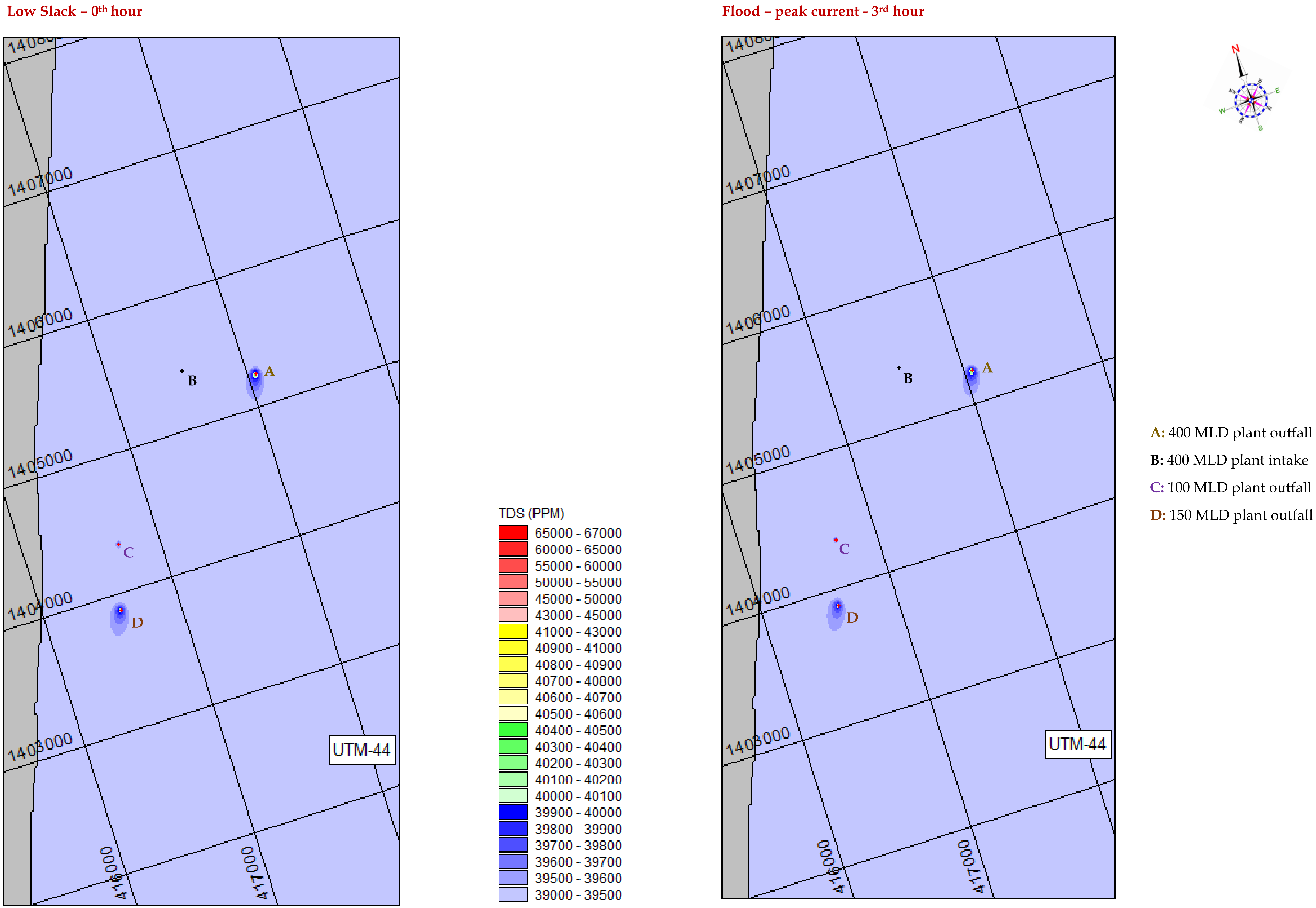


FIG. 6.12(A). SECONDARY DISPERSION – NE MONSOON - NEAP TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

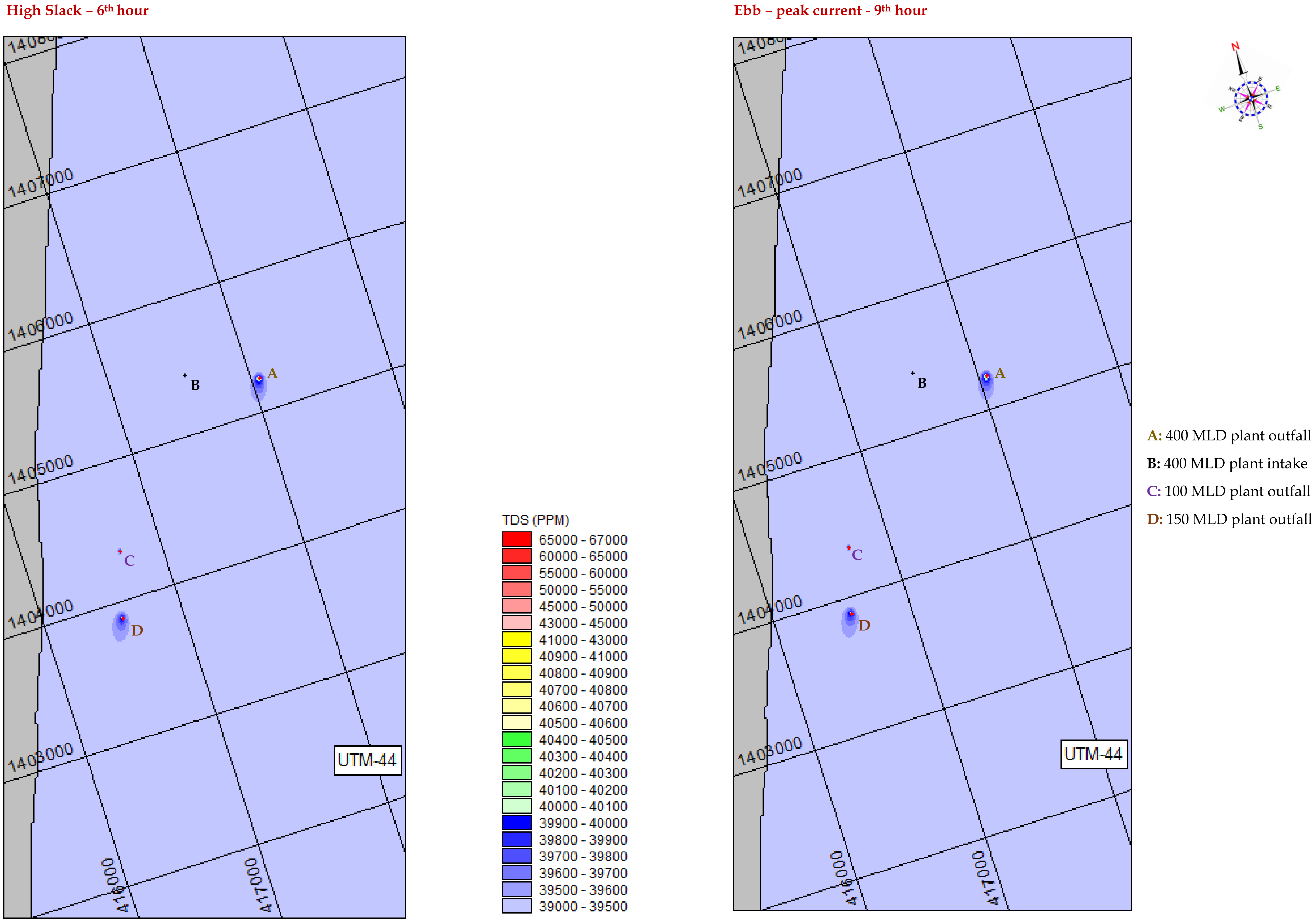


FIG. 6.12(B). SECONDARY DISPERSION – NE MONSOON - NEAP TIDE – CASE II (ADOPTED IN JICA STUDY) – (TDS)

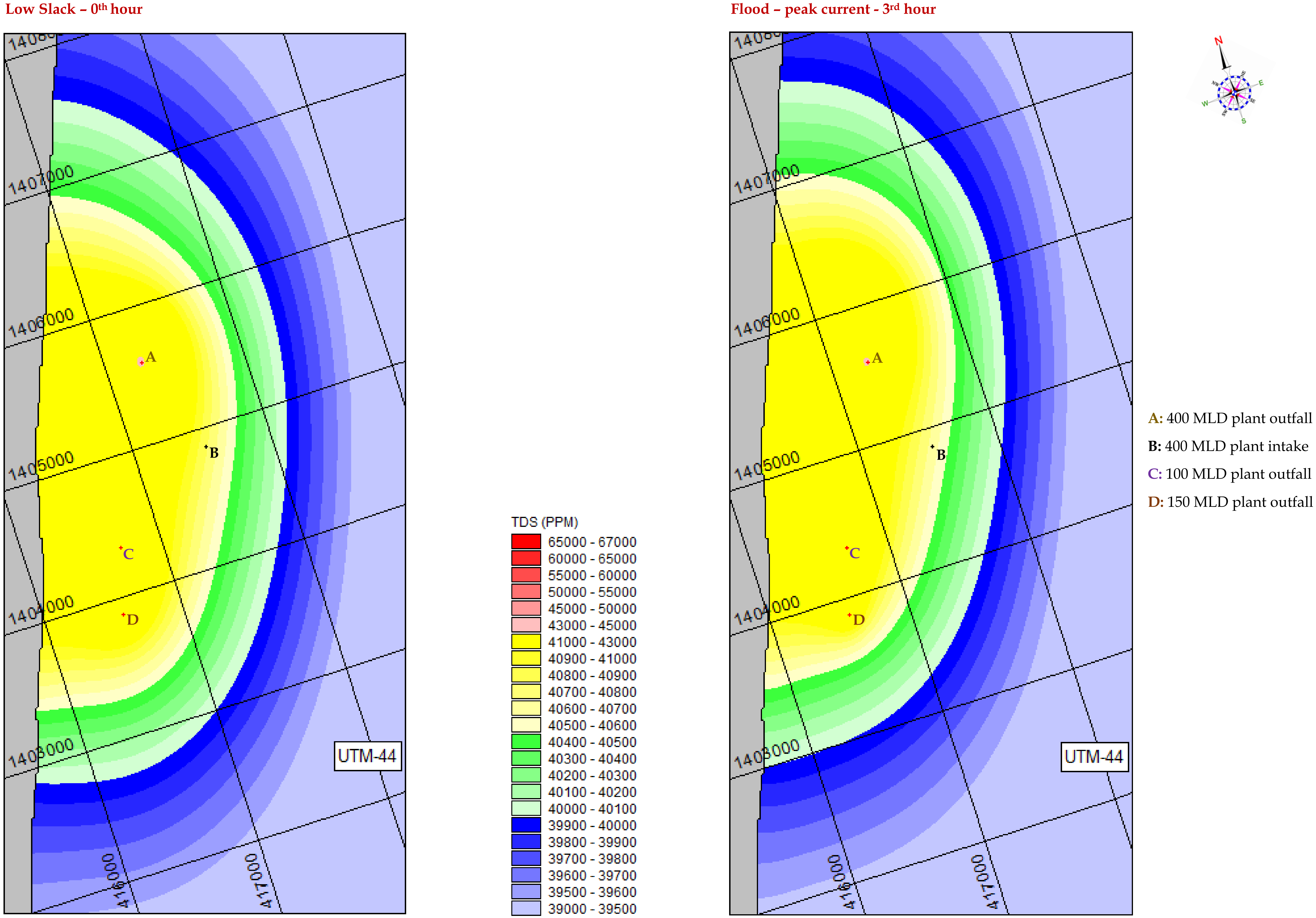


FIG. 6.13(A). SECONDARY DISPERSION – FAIR WEATHER - SPRING TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

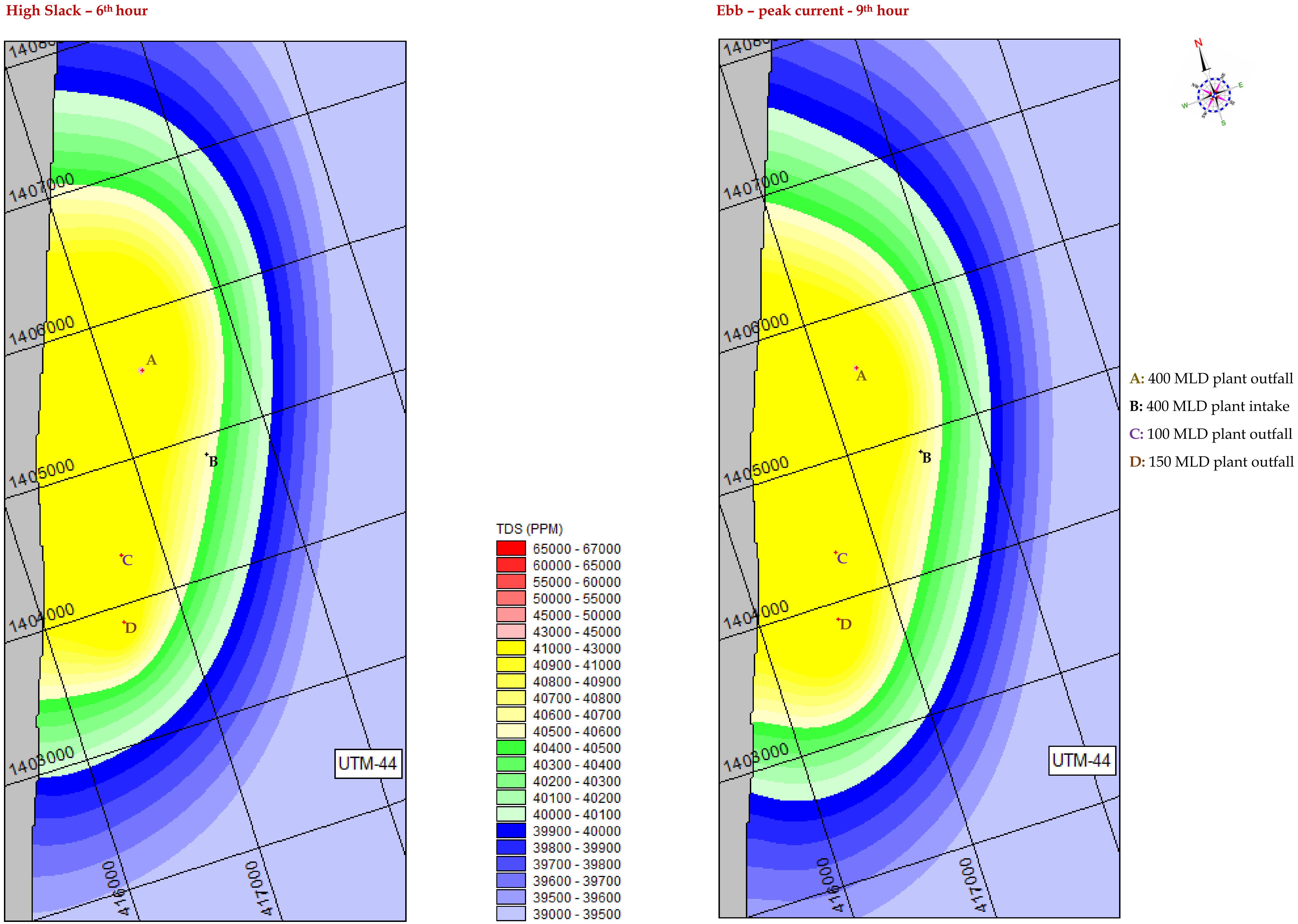


FIG. 6.13(B). SECONDARY DISPERSION – FAIR WEATHER - SPRING TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

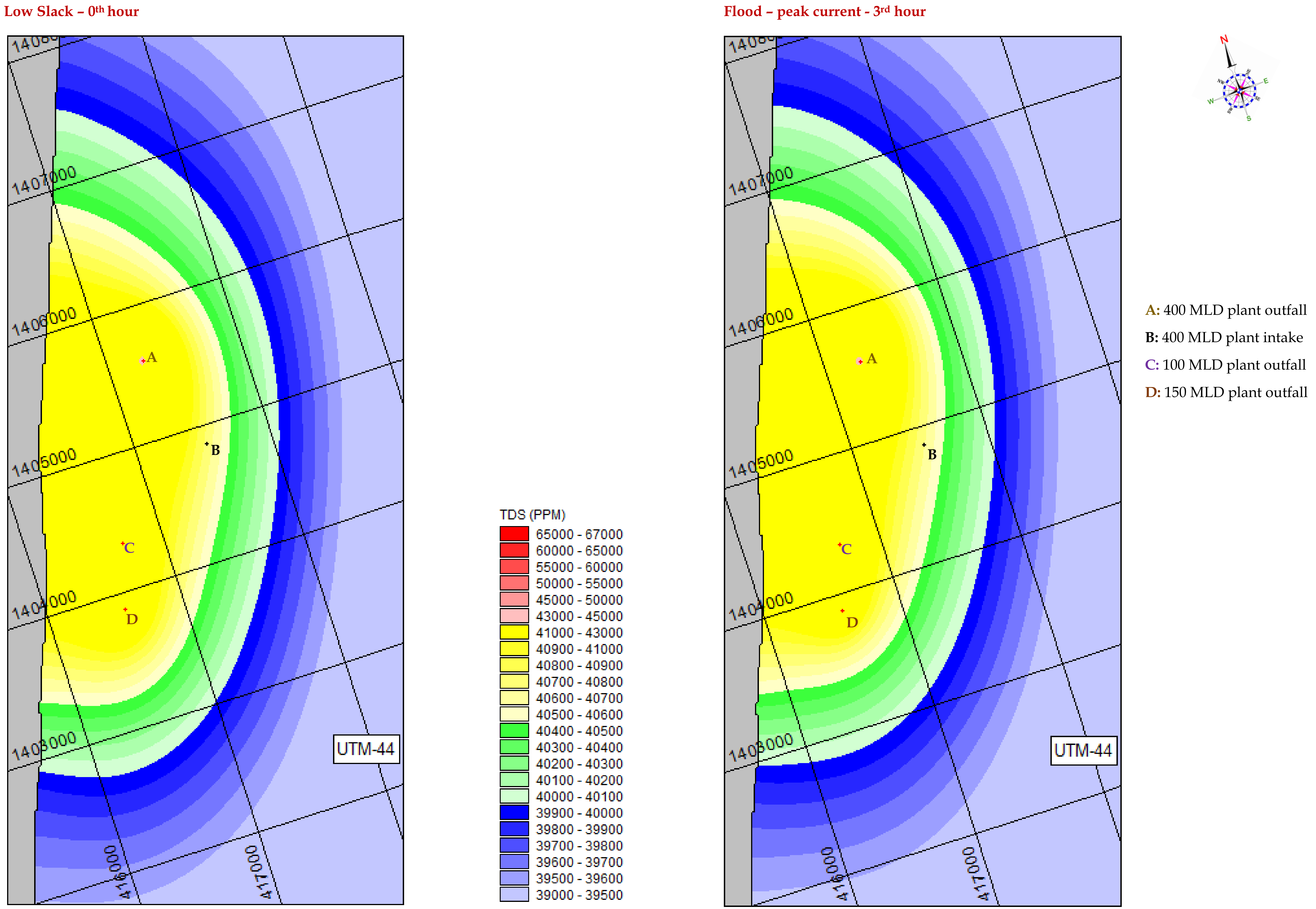


FIG. 6.14(A). SECONDARY DISPERSION – FAIR WEATHER - NEAP TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

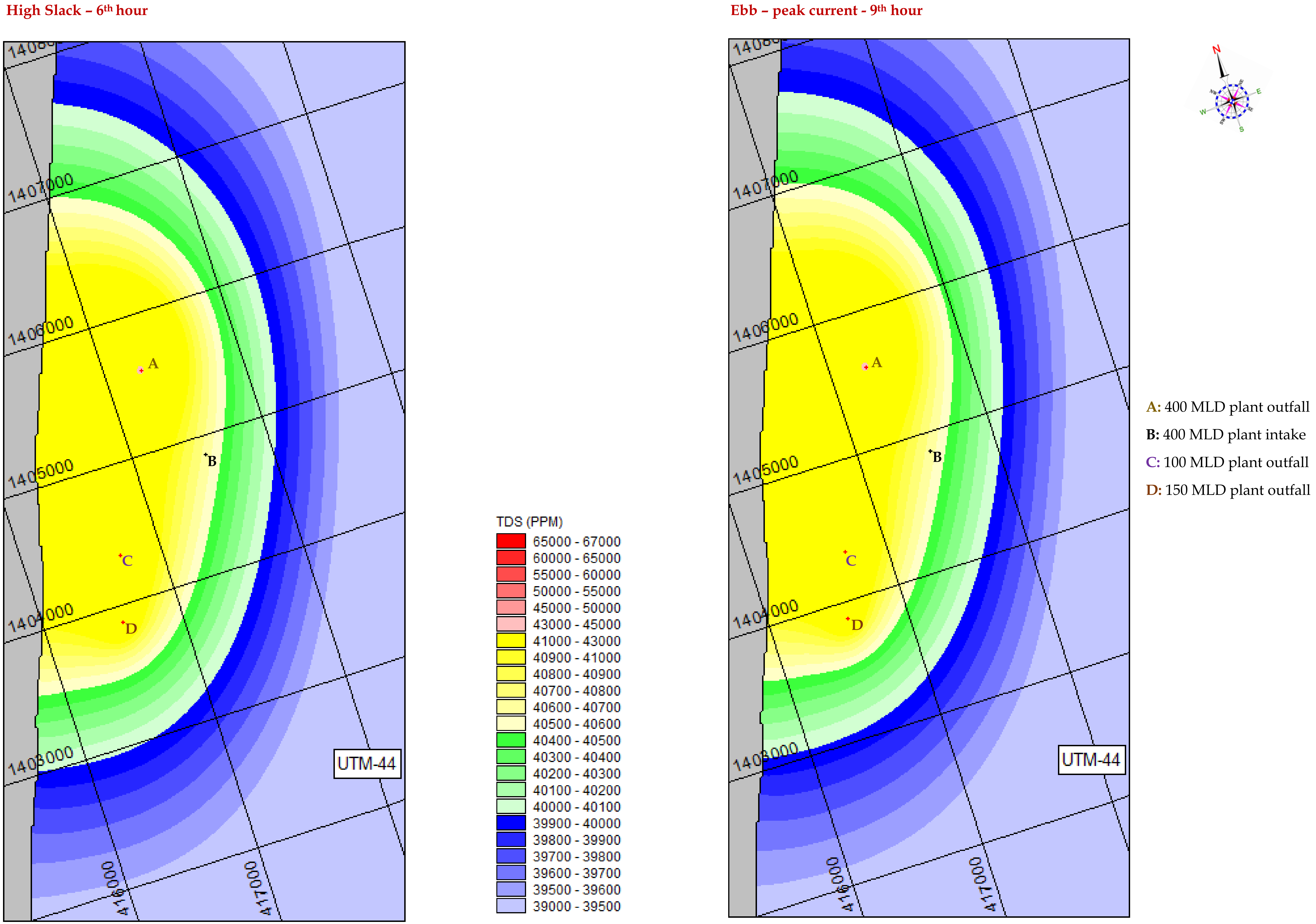


FIG. 6.14(B). SECONDARY DISPERSION – FAIR WEATHER - NEAP TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

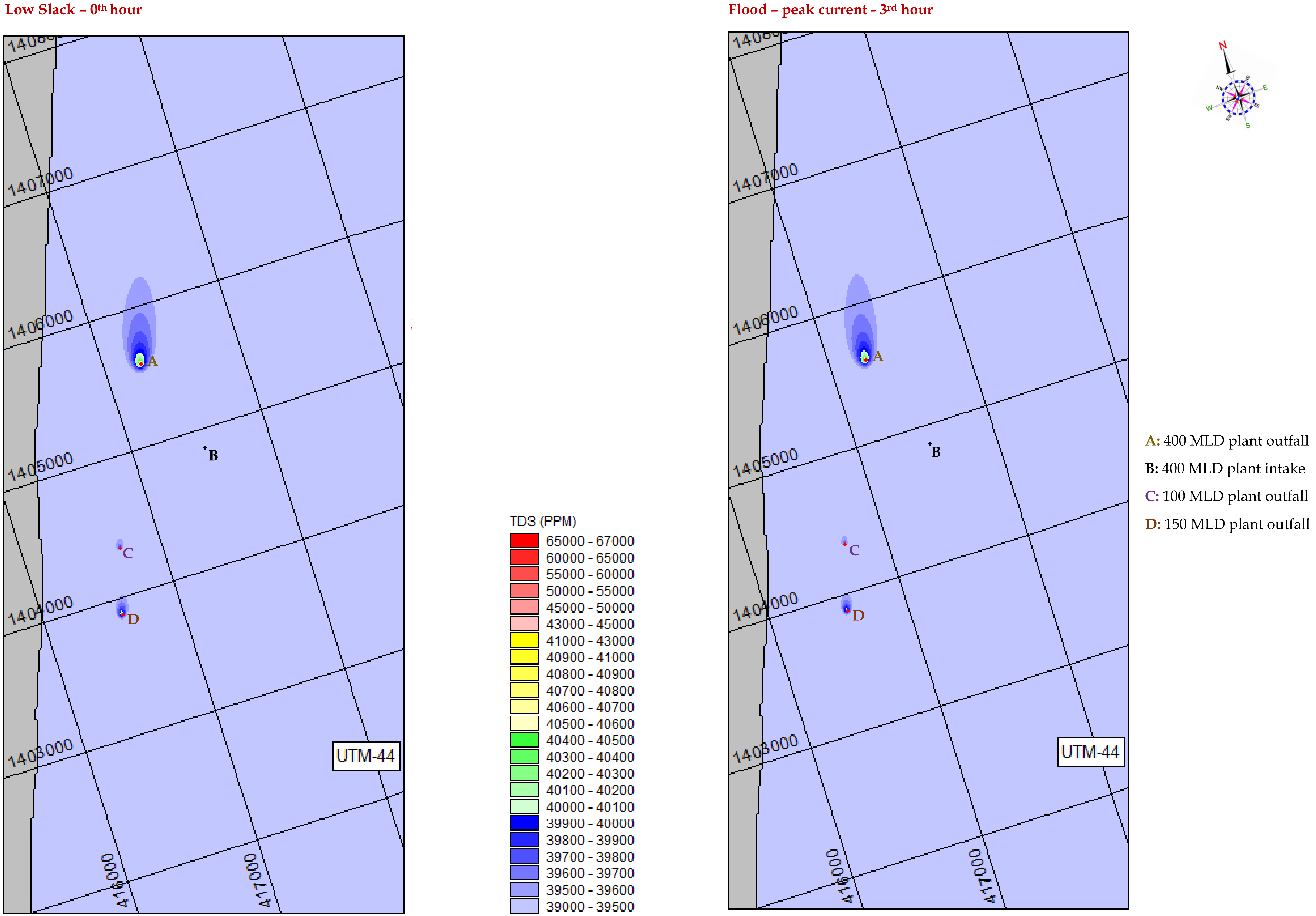


FIG. 6.15(A). SECONDARY DISPERSION – SW MONSOON - SPRING TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

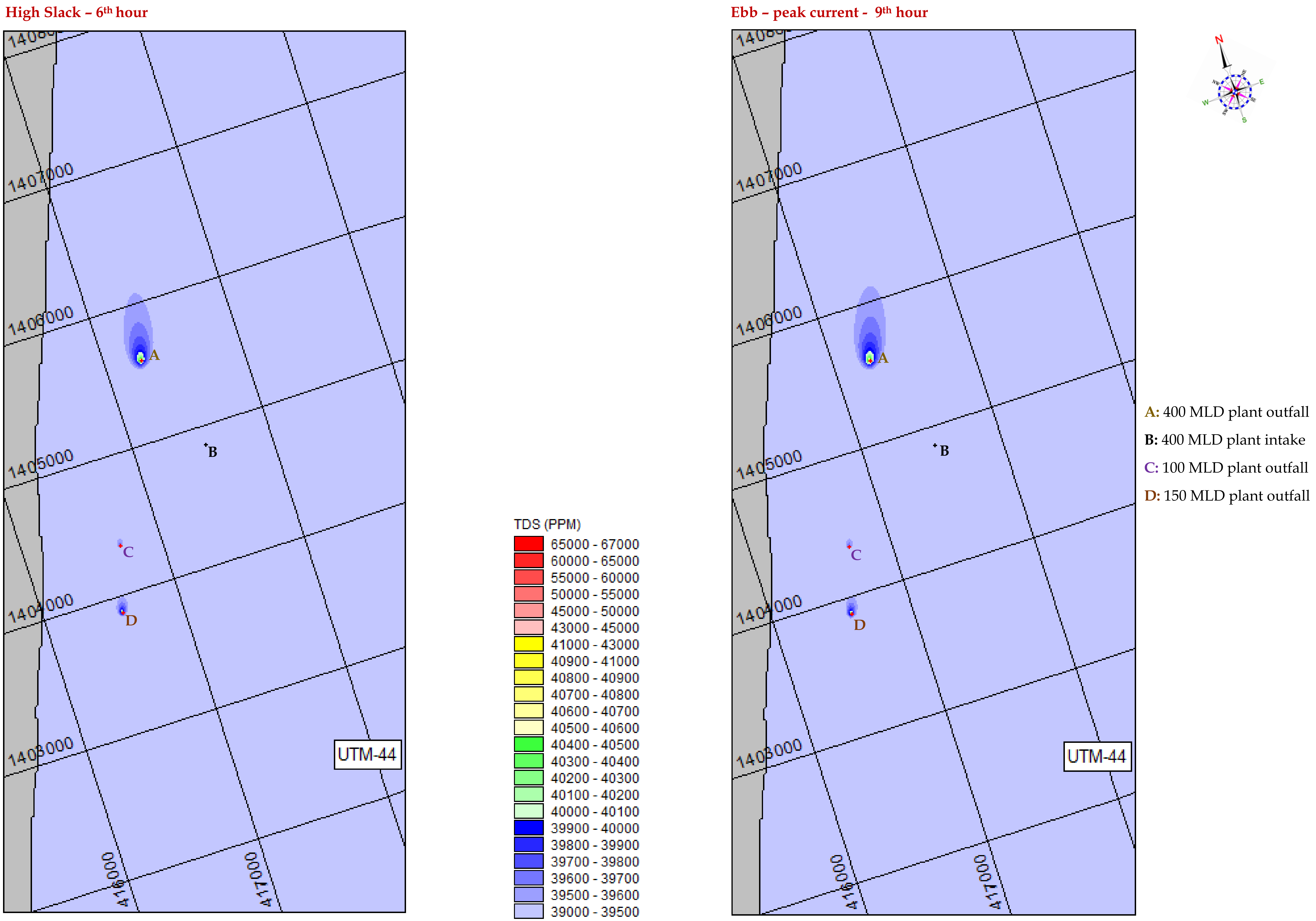


FIG. 6.15(B). SECONDARY DISPERSION – SW MONSOON - SPRING TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

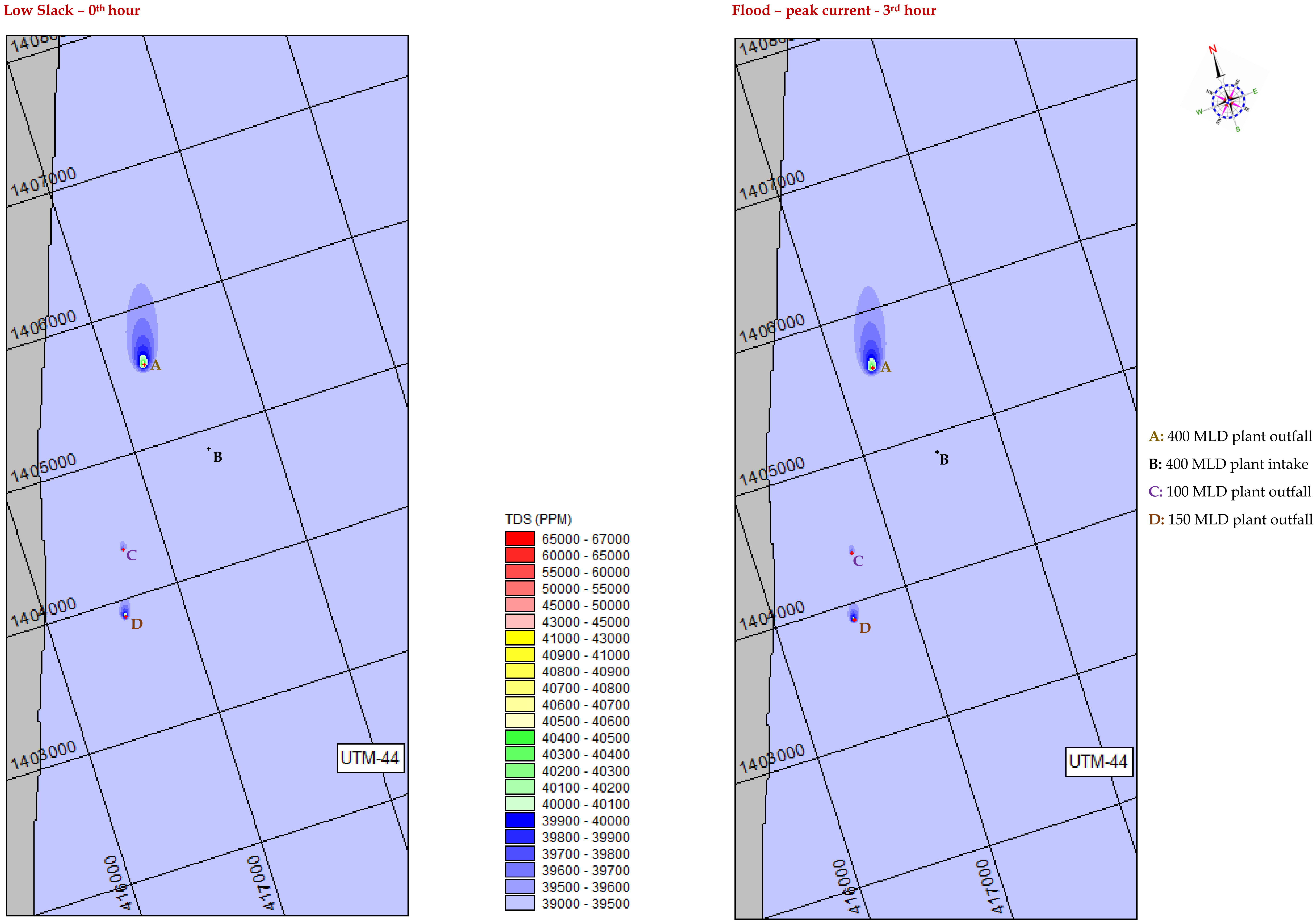


FIG. 6.16(A). SECONDARY DISPERSION – SW MONSOON - NEAP TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

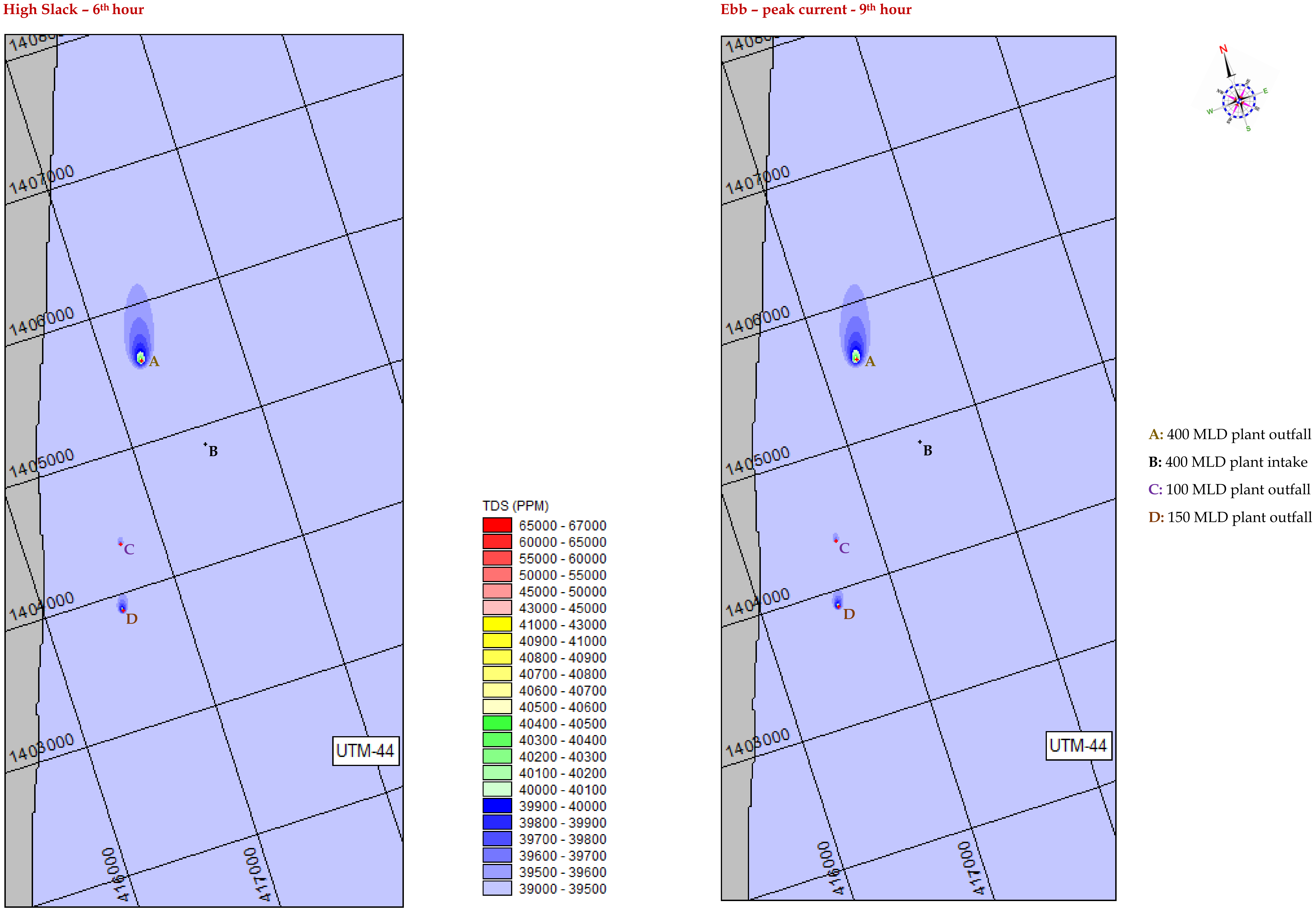


FIG. 6.16(B). SECONDARY DISPERSION – SW MONSOON - NEAP TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

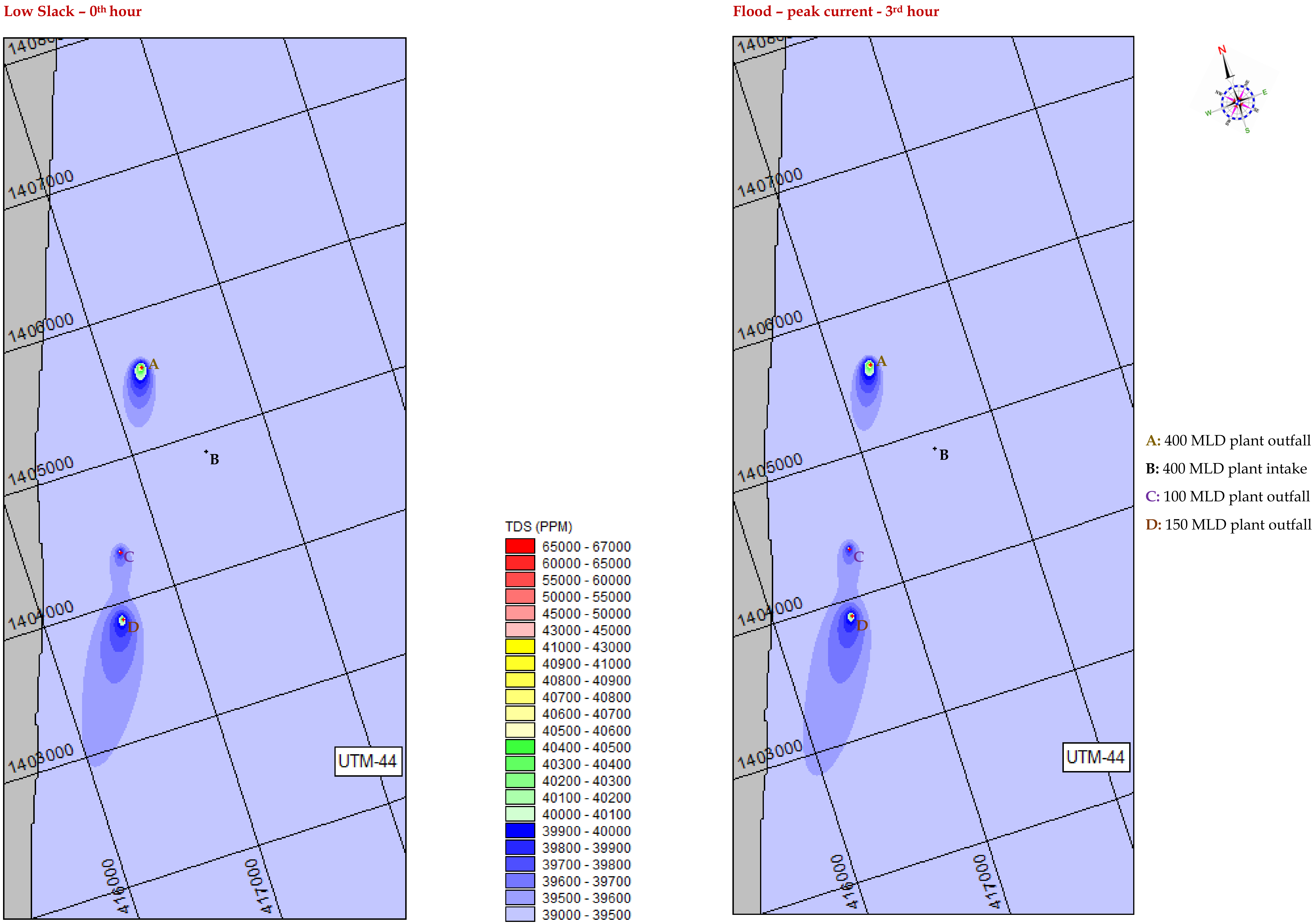


FIG. 6.17(A). SECONDARY DISPERSION – NE MONSOON - SPRING TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

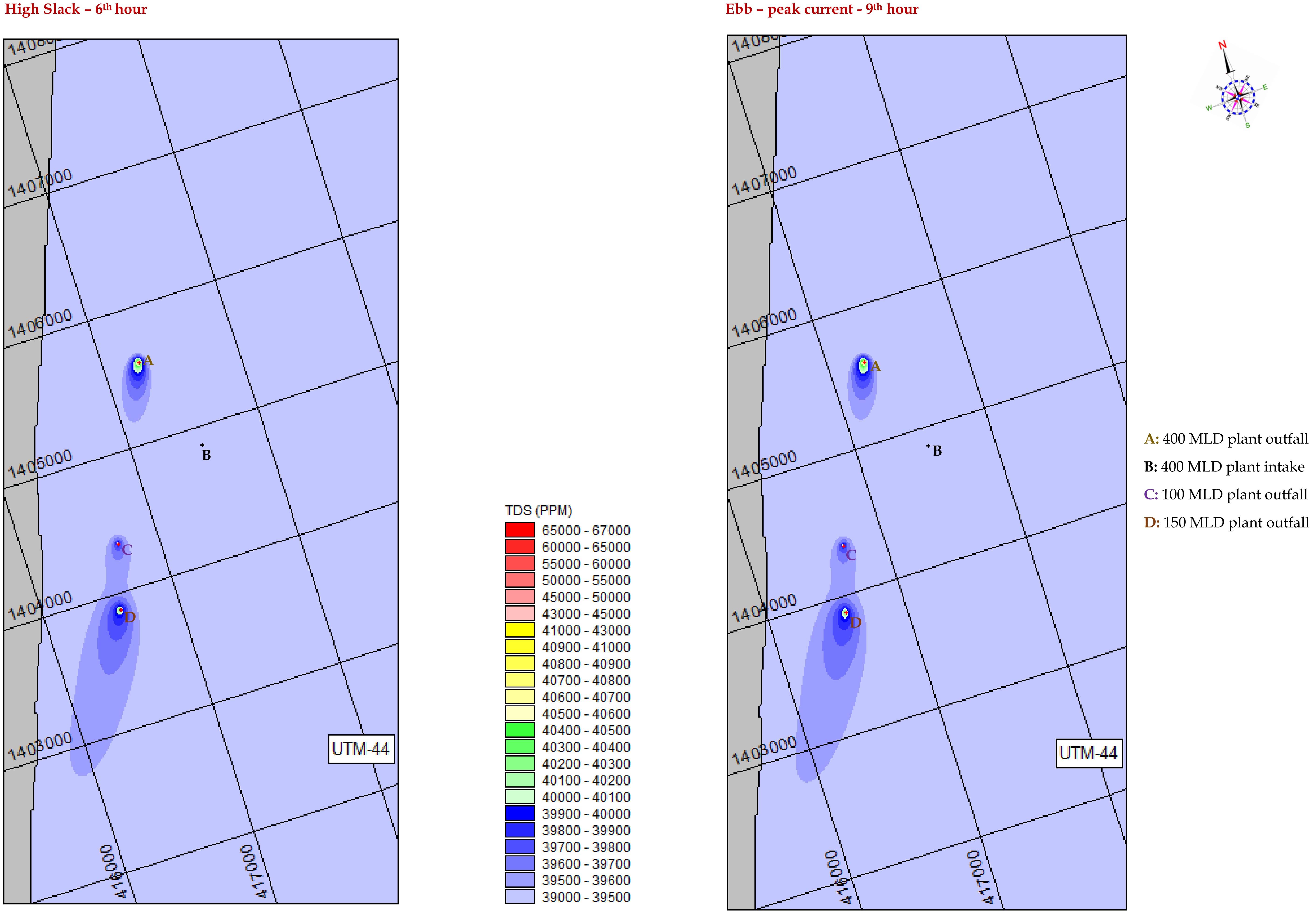


FIG. 6.17(B). SECONDARY DISPERSION – NE MONSOON - SPRING TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

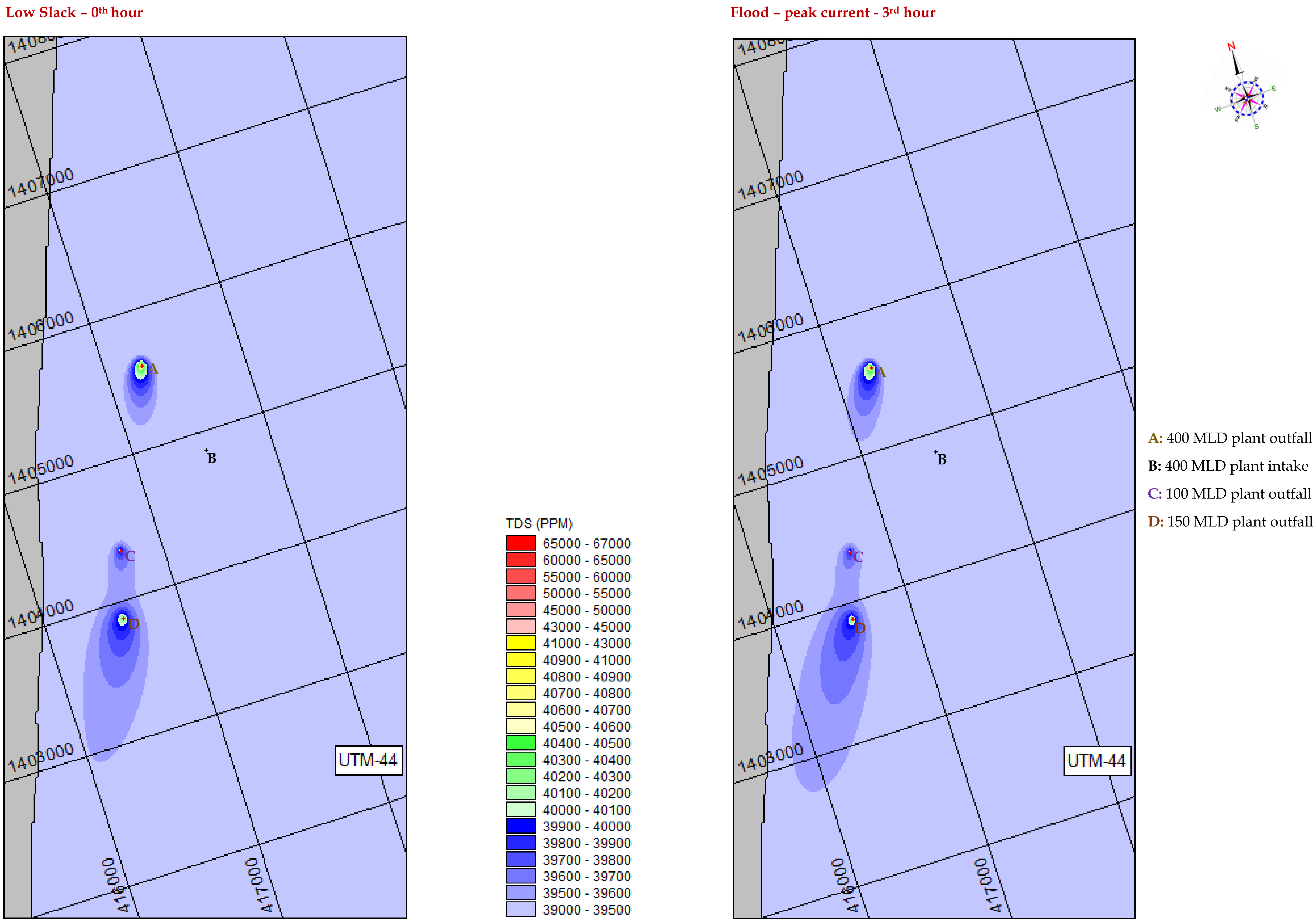


Fig. 6.18(A). SECONDARY DISPERSION – NE MONSOON - NEAP TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)

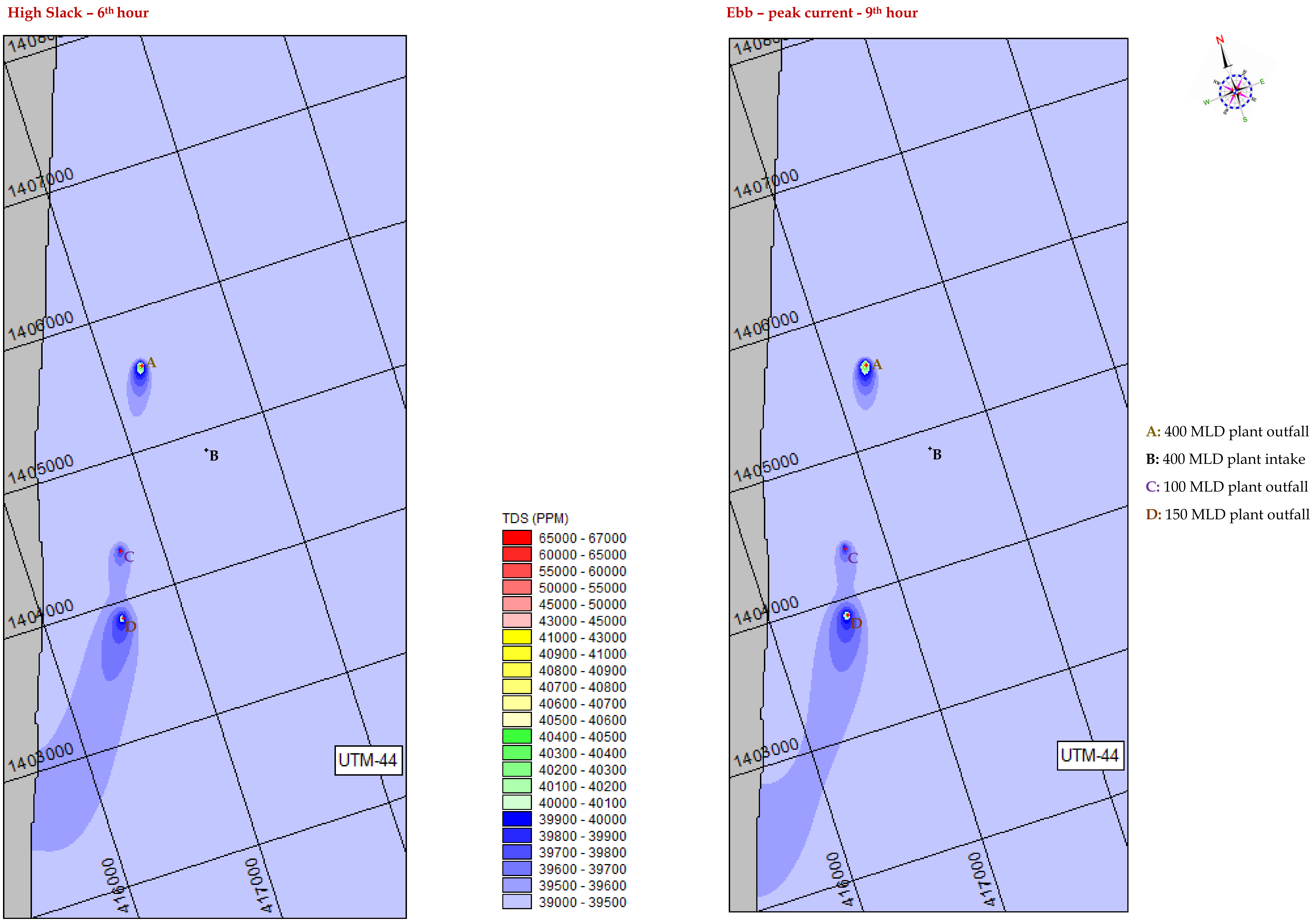


FIG. 6.18(B). SECONDARY DISPERSION – NE MONSOON - NEAP TIDE – CASE III (SUGGESTED BY INDOMER) – (TDS)