## Workshop on Integrating Climate Action in the Development Planning of Puducherry Union Territory

# ENHANCING CLIMATE RESILIENCE THROUGH INTEGRATED WATER RESOURCE MANAGEMENT


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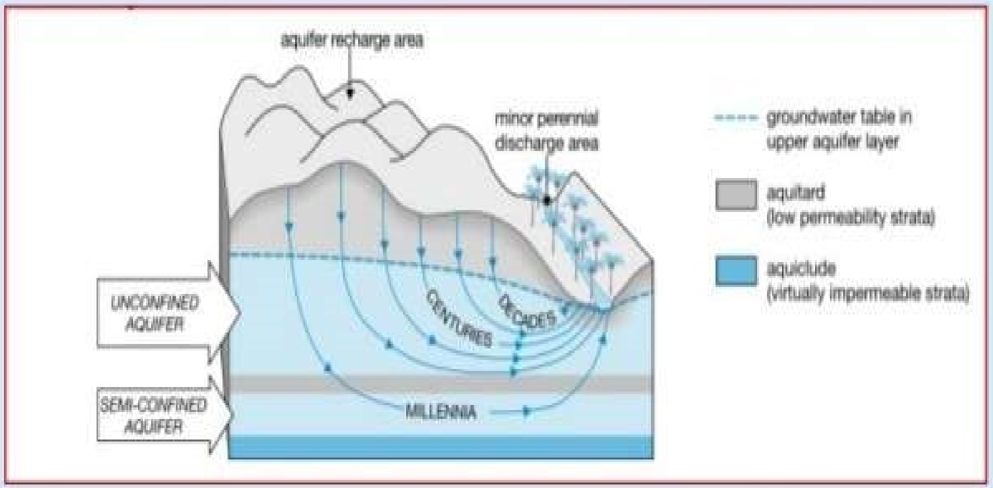
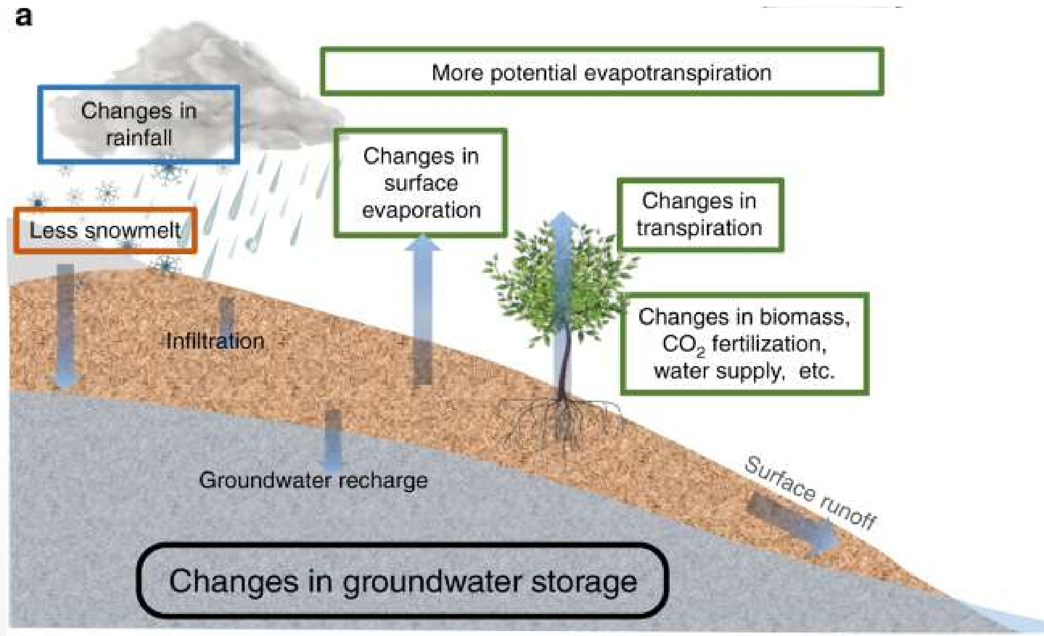
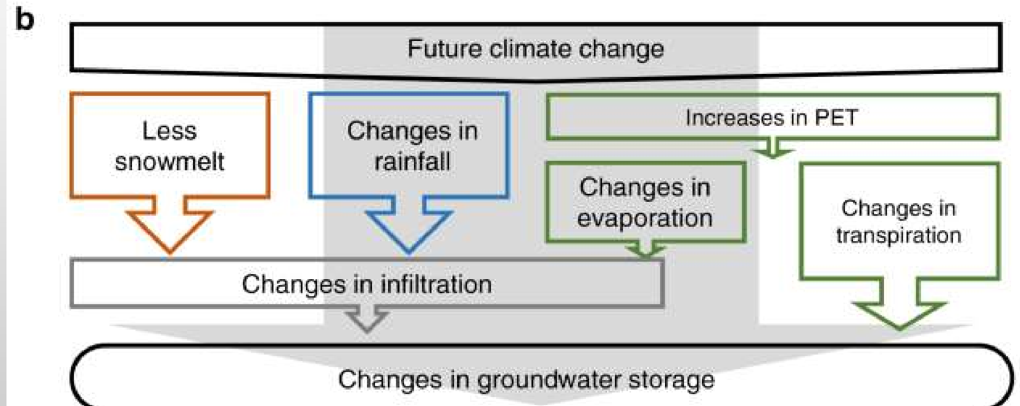
# CLIMATE CHANGE IMPACTS ON GROUNDWATER




- Recharge
- Discharge
- Storage
- Quality

- Temperature
- Precipitation
- Evapotranspiration
- Sea level rise
- Soil moisture



# ASSESSMENT OF CLIMATE CHANGE OVER THE INDIAN REGION: MINISTRY OF EARTH SCIENCES (MOES, 2020)

**TEMPERATURE:**

- DURING 1901-2008, THE AVERAGE TEMPERATURE OF INDIA HAS RISEN BY 0.7°C.
- TEMPERATURE IN INDIA IS EXPECTED TO RISE BY 4.4°C BY END OF THIS CENTURY DUE TO GREEN HOUSE GASES EMISSION.
- THE RISE WILL INCREASE HEAT WAVES (APRIL AND JUNE) OVER INDIA BY 3-4 TIMES BY THE END OF THIS CENTURY WHICH WILL ALSO INCREASE DROUGHT INTENSITY.

**RAINFALL:**

- THE INDIAN MONSOON VARIABILITY IS PROJECTED AS 14% BY 2100 AND MAY GO UP BY 22.5%.
- DECLINE IN RAINFALL (UP TO 6%) DURING SUMMER MONSOON BETWEEN 1950 TO 2015, WELL WITNESSED IN INDO-GANGETIC AND WESTERN GHATS REGION.
- FREQUENCY OF DRY SPELLS AND WET SPELLS DURING MONSOON HAS INCREASED BY 27% AND 75% RESULTING IN DROUGHTS.

**CHANGES IN THE HIMALAYAN REGION:**

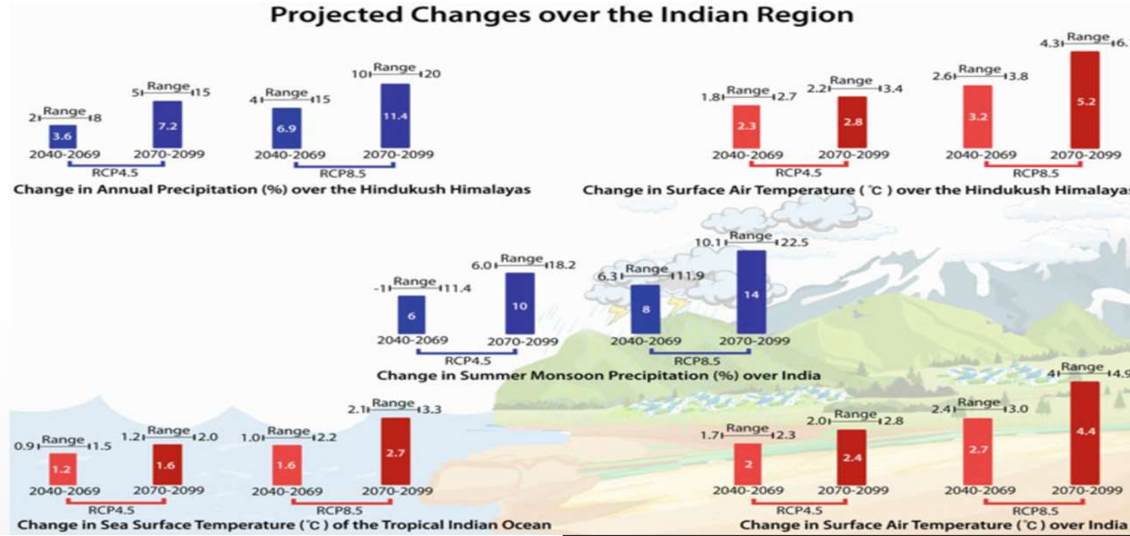
- HINDU KUSH HIMALAYAS HAVE WITNESSED RISE IN TEMPERATURE (1.3°C) RESULTING IN SNOWFALL DECLINE.
- FURTHER DECLINE IN SNOW FALL IS ALSO WITNESSED.
- TEMPERATURE IS PROJECTED TO RISE BY 5.2°C.

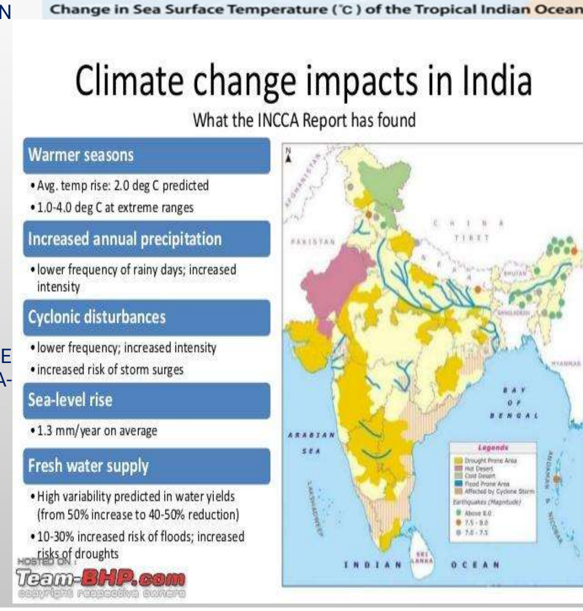
**SEA LEVEL RISE:**

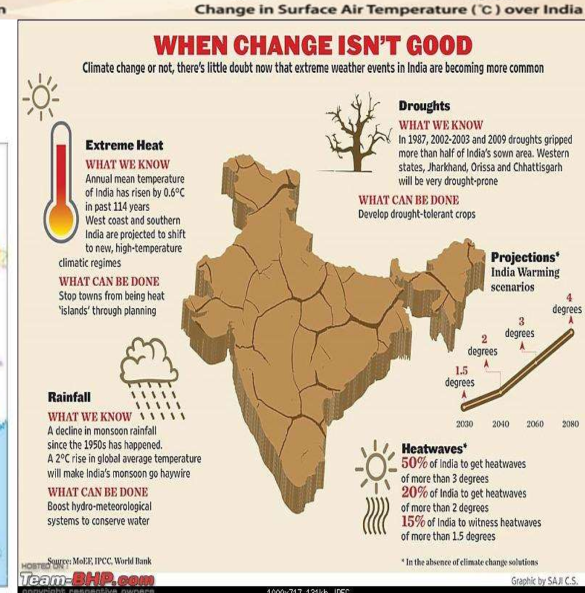
- INDIAN OCEAN HAVE EXPERIENCED SEA LEVEL RISE AT A RATE OF 1.06 TO 1.75 MM.
- FURTHER IT IS PROJECTED TO INCREASE BY 300 MM.

**TROPICAL CYCLONES:**

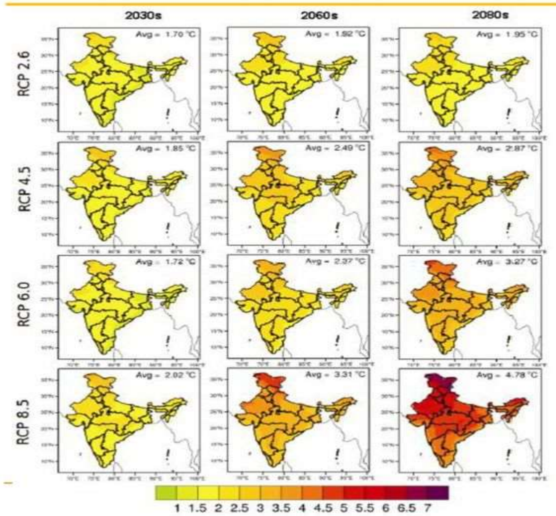
- THE FREQUENCY OF SEVERE CYCLONIC STORMS HAVE INCREASED, RISE IN AVERAGE TEMPERATURE, DECREASE IN THE MONSOON PRECIPITATION, RISE IN RAINFALL, DROUGHTS, SEA-LEVEL, INCREASED INTENSITY OF CYCLONES, ETC.



## Climate projections to 2100 - Temperature




- Annual Mean Temperature increases ( 2030 to 2100):
  - 2.0 to 4.8 for BAU
  - 1.7 - 2°C (RCP2.6)
- More increase in night temperature and post monsoon
- Increase in frequency of extreme temperatures (1-in-20 year hottest day *likely* to become a 1-in-2 year event)
- Consecutive day warm spells beyond 90th percentile, lengthen to 150–200 days under (BAU), but only to 30–45 days under RCP2.6

Fig source; Chaturvedi et al, 2012

## Climate projections to 2100 - Rainfall

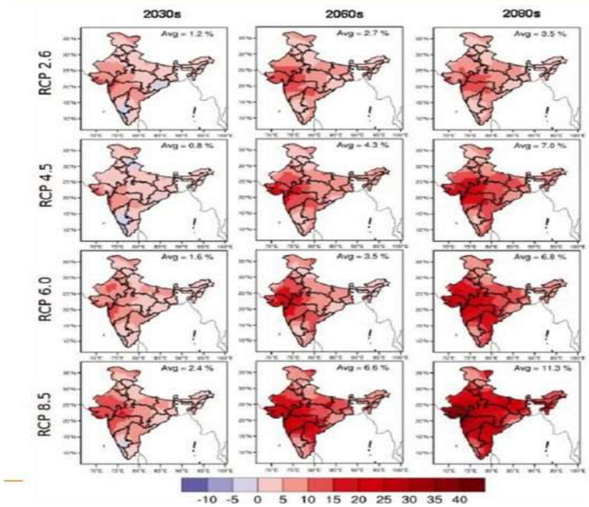
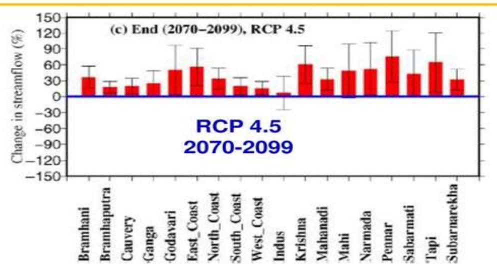
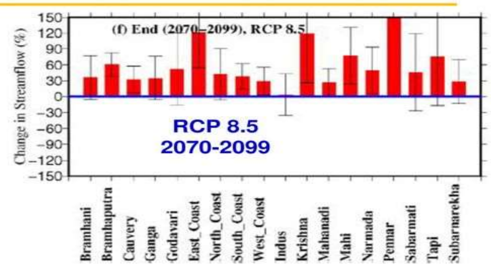



Fig source; Chaturvedi et al, 2012

- Mean annual precipitation: increases 4-5% by 2030s; 6 - 14% by 2080s; except for a few regions in short term projections (2030s); increase in inter-annual variability
- Years with above normal monsoon rainfall expected to increase
- Extreme precipitation: increase in frequency of extreme precipitation (>40 mm/day) days for 2060s and beyond; 30-40% increase in frequency of > 100 mm/day events
- 1-in-20 year annual maximum daily precipitation *likely* to become a 1-in-5 to 1-in-15-year event by the end of the 21st century
- Frequency and intensity of droughts increase in lower latitudes
- Frequency and intensity of floods increases

## Climate change impacts on water resources – streamflow in major basins

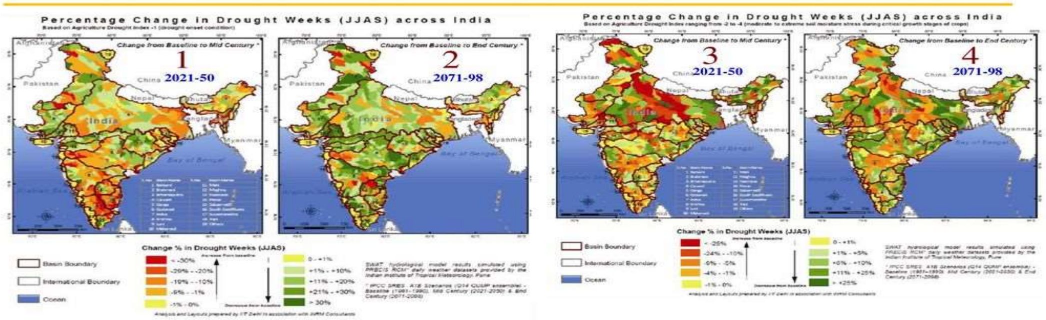



- In majority of river basins, streamflow likely to increase
- Monsoon season streamflow increase > 40% in 8/9 basins for RCP 4.5/RCP8.5
- Streamflow is more sensitive to changes in rainfall than temperature
- Evapotranspiration increases up to 10% in both scenarios

Source: Mishra & Lihare 2016

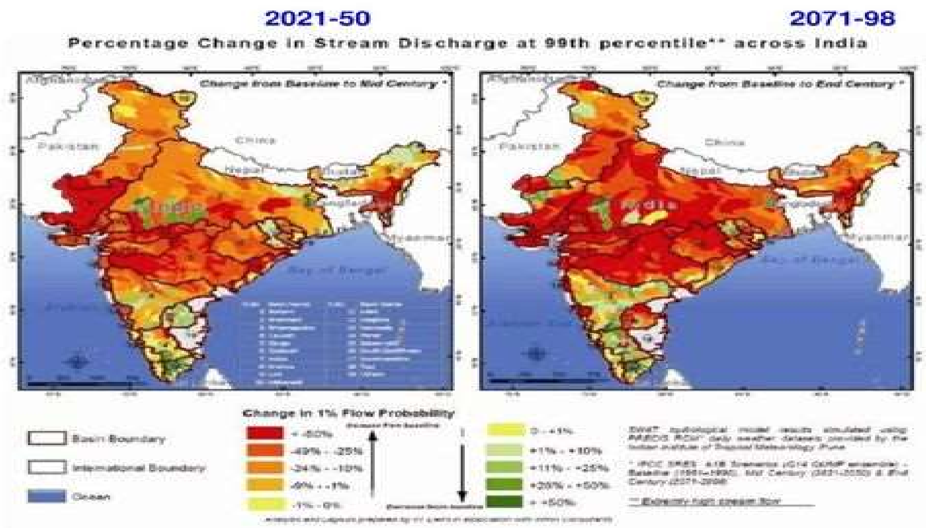
## Climate change impacts on water resources – drought (moderate(1,2), moderate to severe (3,4))

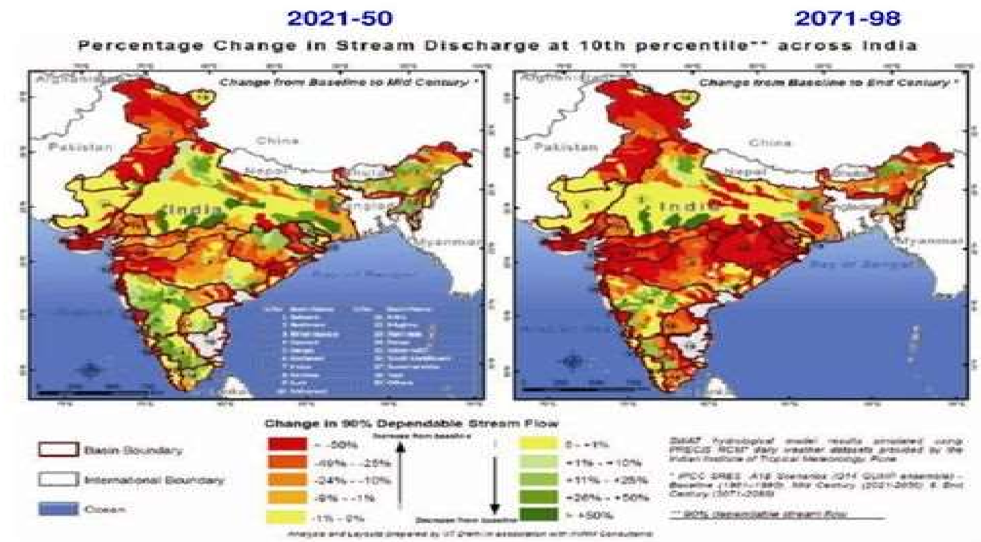



- estimates based on weekly soil moisture deficit
- increase in moderate and severe drought frequencies and areal extent despite increase in rainfall (marginal improvement towards end of century)

Source: Gosain et al, 2012

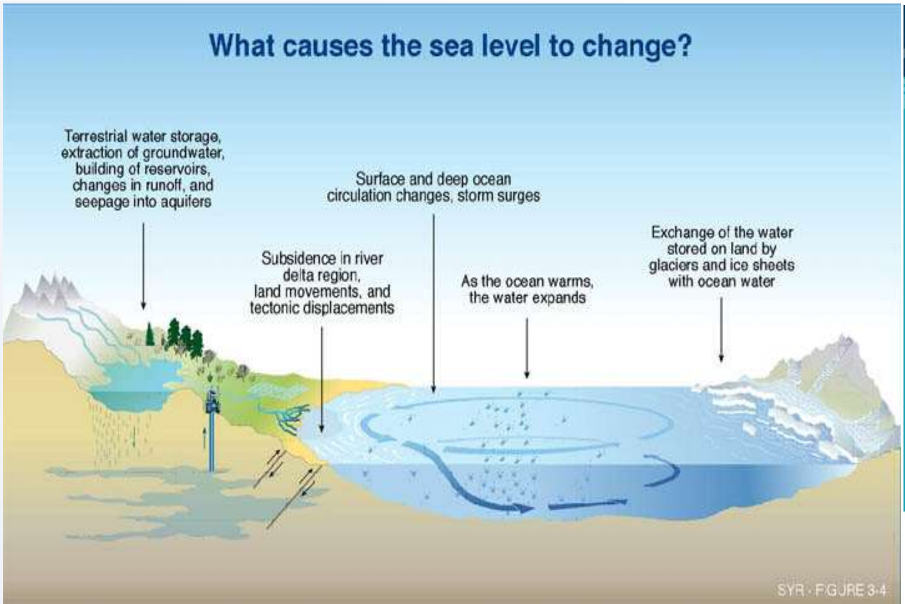
# Climate change impacts on water resources – extreme flows, dependable flows

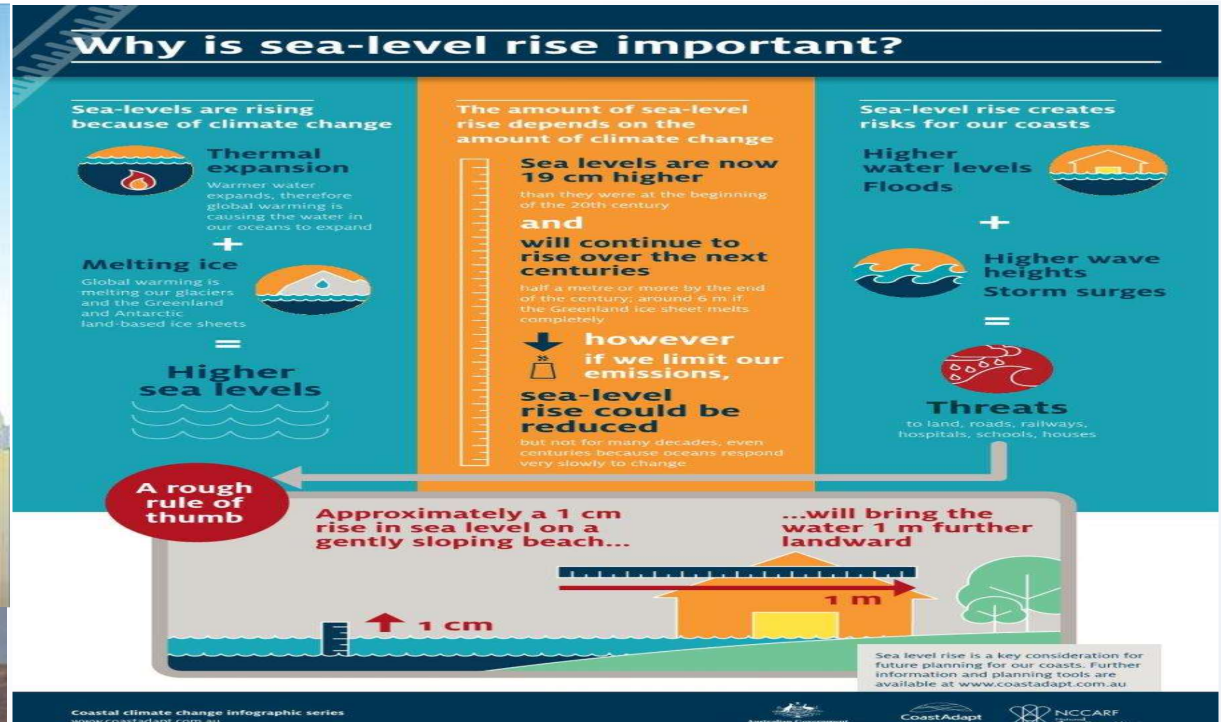


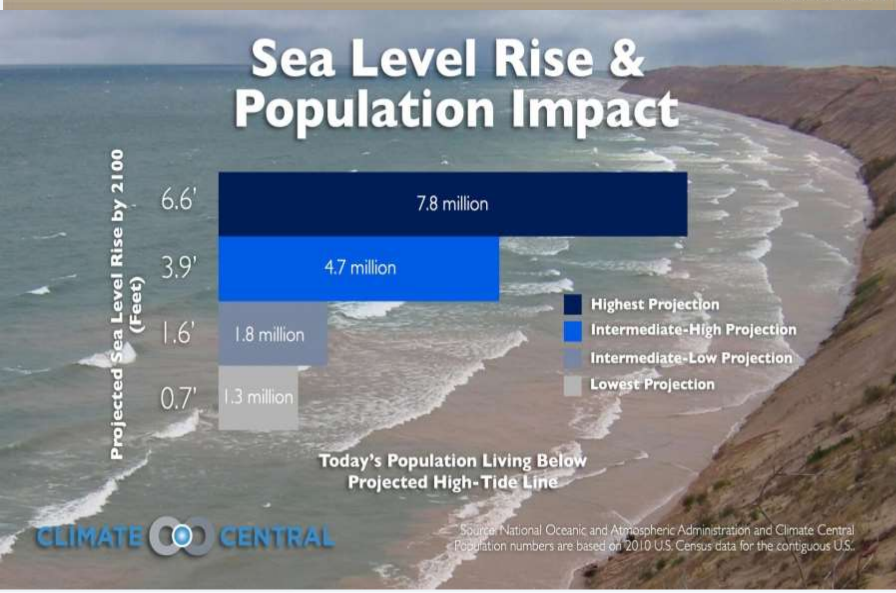



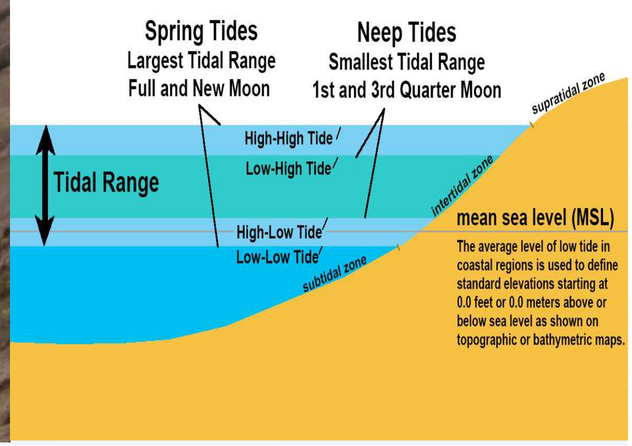

- Extreme flows (99th percentile) increase by 10-50% leading to flooding in majority of the river basins; few sub-basins show some decrease in the peak flows
- dependable (10th percentile) flows also increase; in some basins in central India dependable flows decline
- Substantial efforts required to develop future water management strategies

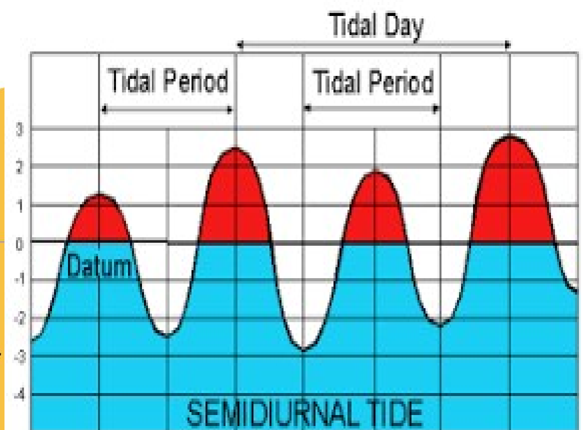
Source: Gosain et al, 2012

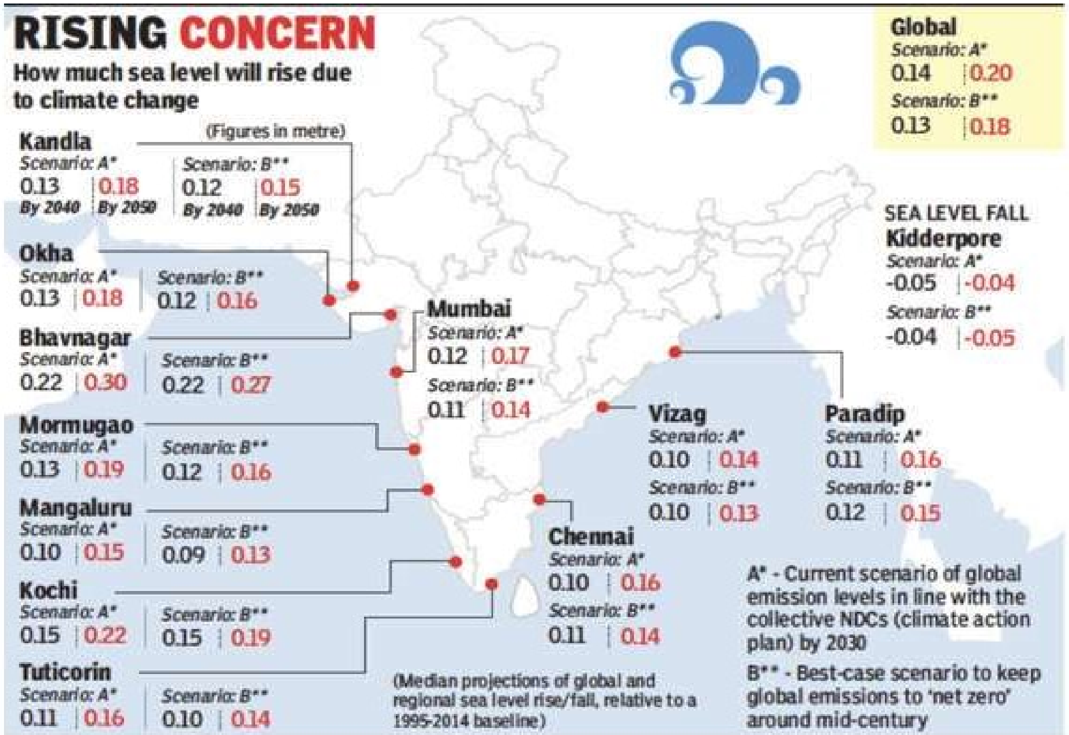

What causes the sea level to change?
Terrestrial water storage, extraction of groundwater, building of reservoirs, changes in runoff, and seepage into aquifers
Surface and deep ocean circulation changes, storm surges
Subsidence in river delta region, land movements, and tectonic displacements
As the ocean warms, the water expands
Exchange of the water stored on land by glaciers and ice sheets with ocean water
SYR - FIGURE 3-4

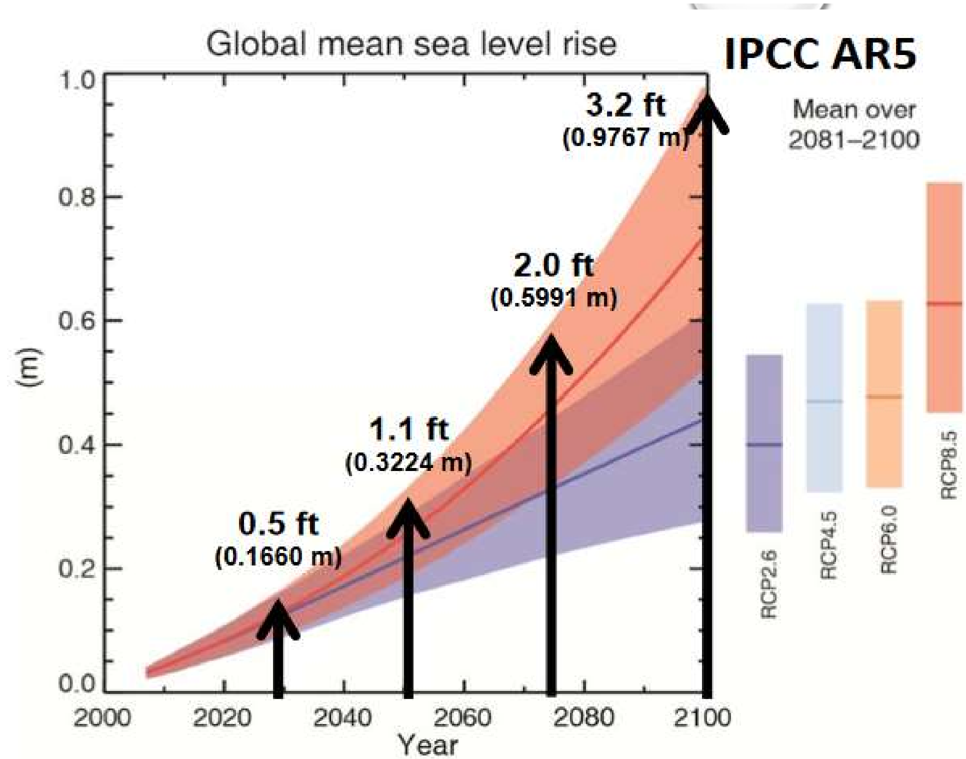

Why is sea-level rise important?
Sea-levels are rising because of climate change
Thermal expansion
Warmer water expands, therefore global warming is causing the water in our oceans to expand
+
Melting ice
Global warming is melting our glaciers and the Greenland and Antarctic land-based ice sheets
=
Higher sea levels
The amount of sea-level rise depends on the amount of climate change
Sea levels are now 19 cm higher
than they were at the beginning of the 20th century
and
will continue to rise over the next centuries
half a metre or more by the end of the century; around 6 m if the Greenland ice sheet melts completely
however
if we limit our emissions,
sea-level rise could be reduced
but not for many decades, even centuries because oceans respond very slowly to change
Sea-level rise creates risks for our coasts
Higher water levels
Floods
+
Higher wave heights
Storm surges
=
Threats
to land, roads, railways, hospitals, schools, houses
A rough rule of thumb
Approximately a 1 cm rise in sea level on a gently sloping beach...
...will bring the water 1 m further landward
1 m
1 cm
Sea level rise is a key consideration for future planning for our coasts. Further information and planning tools are available at www.coastadapt.com.au
Coastal climate change infographic series
www.coastadapt.com.au
CoastAdapt
NCCARF


Sea Level Rise & Population Impact
Projected Sea Level Rise by 2100 (Feet)
6.6'
3.9'
1.6'
0.7'
7.8 million
4.7 million
1.8 million
1.3 million
Highest Projection
Intermediate-High Projection
Intermediate-Low Projection
Lowest Projection
Today's Population Living Below Projected High-Tide Line
CLIMATE CENTRAL
Source: National Oceanic and Atmospheric Administration and Climate Central
Population numbers are based on 2010 U.S. Census data for the contiguous U.S.


Spring Tides
Largest Tidal Range
Full and New Moon
Neap Tides
Smallest Tidal Range
1st and 3rd Quarter Moon
supratidal zone
High-High Tide
Low-High Tide
Tidal Range
intertidal zone
High-Low Tide
Low-Low Tide
subtidal zone
mean sea level (MSL)
The average level of low tide in coastal regions is used to define standard elevations starting at 0.0 feet or 0.0 meters above or below sea level as shown on topographic or bathymetric maps.


Tidal Day
Tidal Period
Tidal Period
Datum
SEMIDIURNAL TIDE




| Rise in sea level in metres | By 2040 | | By 2050 | |
|---|---|---|---|---|
| | A* | B** | A* | B** |
| Mumbai | 0.12 | 0.11 | 0.17 | 0.14 |
| Mangaluru | 0.10 | 0.09 | 0.15 | 0.13 |
| Kochi | 0.15 | 0.15 | 0.22 | 0.19 |
| Chennai | 0.10 | 0.11 | 0.16 | 0.14 |
| Vizag | 0.10 | 0.10 | 0.14 | 0.13 |
| Global | 0.14 | 0.13 | 0.20 | 0.18 |

**A*** - Current scenario of global emission level in line with the collective nationally determined contributions (climate action plan) by 2030
**B**** - Best-case scenario to keep global emission to 'net zero' around mid-century
(Median projections of global and regional sea level rise or fall, relative to a 1995-2014 baseline)

**Representative concentration pathways**

| RCP | Forcing | Temperature | Emission Trend |
|---|---|---|---|
| 1.9 | 1.9W/m2 | ~1.5°C | Very Strongly Declining Emissions |
| 2.6 | 2.6W/m2 | ~2.0°C | Strongly Declining Emissions |
| 4.5 | 4.5W/m2 | ~2.4°C | Slowly Declining Emissions |
| 6.0 | 6.0W/m2 | ~2.8°C | Stabilising Emissions |
| 8.5 | 8.5W/m2 | ~4.3°C | Rising Emissions |

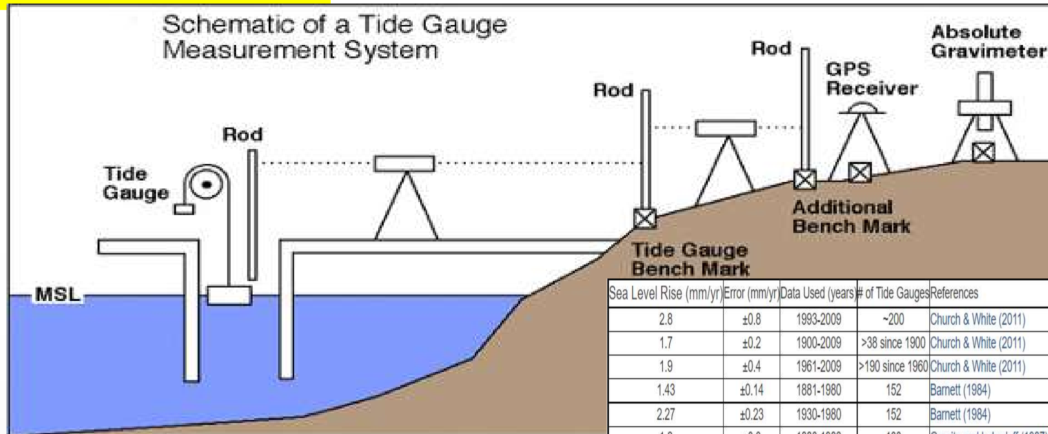
# MEASURING SEA LEVEL

## Measuring sea level using tide gauges

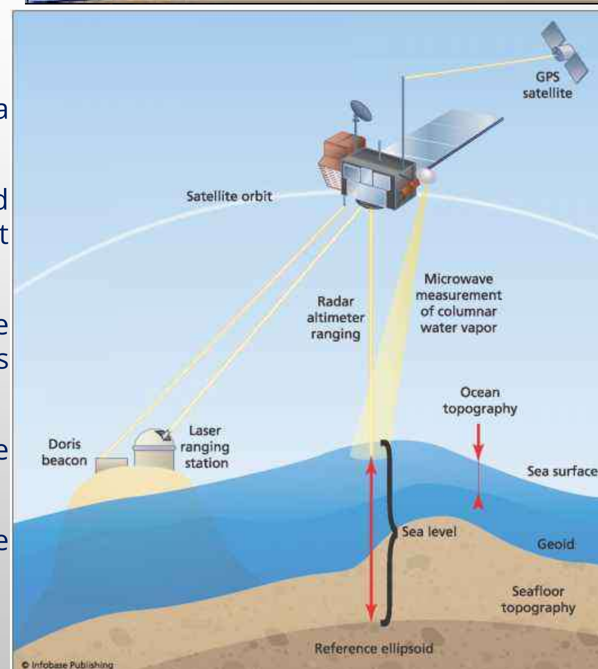
- Measuring sea level (SL) using tide gauges provide long and reliable records of water levels that can be used to isolate sea level change trends.
- The tide gauge detect high and low points of tides in a given period of time.
- These data points are also important for detecting water levels during storms and other events as well as in the long-term investigation of relative water level change (rise or fall).
- Tide levels are also measured by floating buoys, which may also be used to detect tsunami waves.

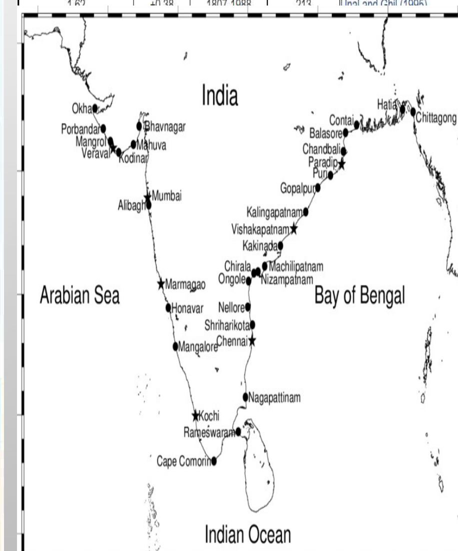
## Measuring sea level using satellite altimetry

- Satellite altimetry with multiple satellites provided much better data resolution and coverage.
- The measurements utilize multi-beam methods that are very precise and can measure changes in elevation on the earth's surface to great precision in the range of centimeters.
- These methods have shown that water bodies are not flat but are incredibly dynamic and have high and low spots due to factors such as gravitational variability.
- Data such as ocean circulation, sea level rise, and wave heights can be measured.
- these measurements have provided insight into the links between the ocean and the atmosphere and how the connections drive climate.



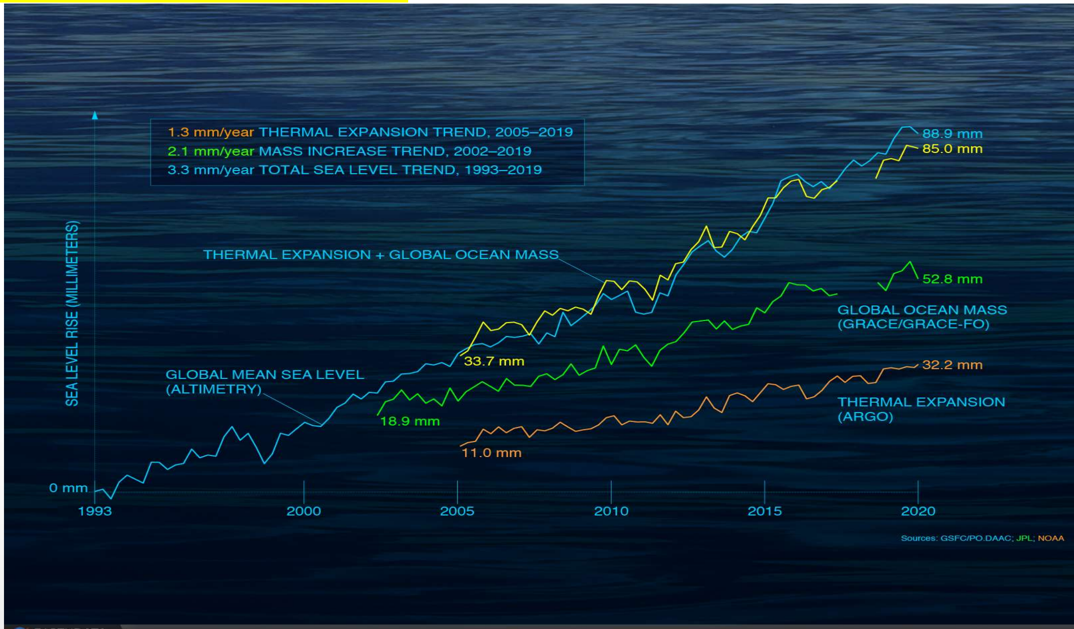

| Sea Level Rise (mm/yr) | Error (mm/yr) | Data Used (years) | # of Tide Gauges | References |
|---|---|---|---|---|
| 2.8 | ±0.8 | 1993-2009 | ~200 | Church & White (2011) |
| 1.7 | ±0.2 | 1900-2009 | >38 since 1900 | Church & White (2011) |
| 1.9 | ±0.4 | 1961-2009 | >190 since 1960 | Church & White (2011) |
| 1.43 | ±0.14 | 1881-1980 | 152 | Barnett (1984) |
| 2.27 | ±0.23 | 1930-1980 | 152 | Barnett (1984) |
| 1.2 | ±0.3 | 1880-1982 | 130 | Gornitz and Lebedeff (1987) |
| 2.4 | ±0.9 | 1920-1970 | 40 | Peltier and Tushingham (1989) |
| 1.75 | ±0.13 | 1900-1979 | 84 | Trupin and Wahr (1990) |
| 1.7 | ±0.5 | N/A | N/A | Nakiboglu and Lambeck (1991) |
| 1.8 | ±0.1 | 1880-1980 | 21 | Douglas (1991) |
| 1.62 | ±0.38 | 1807-1988 | 213 | Unal and Ghil (1995) |

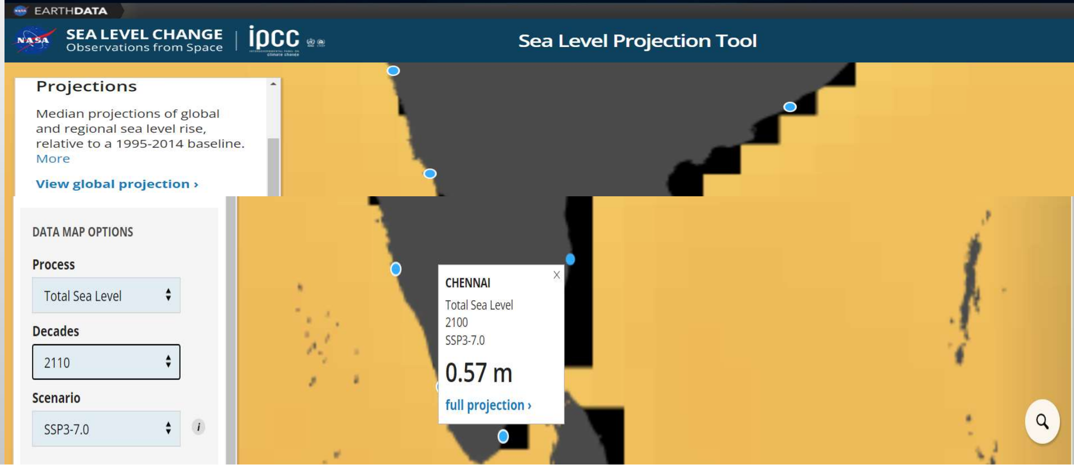


# MODELS ON SEA LEVEL RISE

- Sea level rise scenarios termed as Global mean sea level (GMSL) scenarios.
- Represent future sea level changes in view of increasing GHG emissions, atmospheric warming and ocean.
- It helps to support planning and decision making in how much sea level rise could occur under what circumstance and by when.
- It also predicts how sea level rise both globally and locally.
- Sea level rise scenarios are generally based upon climate model outputs.
- **Climate models simulate different responses, like how ocean might warm, where ice melts and how additional water disperses around the world's oceans and affects circulation patterns.**
- These responses differ under models that use different bounding conditions like varying GHG emissions and ocean and atmospheric warming projections for future sea level rise.
- Thus sea level rise scenarios help us plan in the face of uncertainty by providing a range of possible futures that help represent a) potential future human-driven greenhouse gas emissions, and b) how earth's physical processes will respond to increased temperatures.



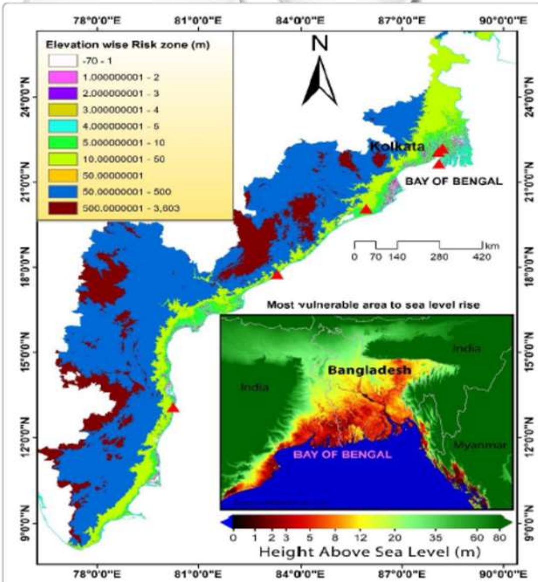



**Figure 9:** Coastal Vulnerability map to sea level rise in 1 m, 2 m, 3 m, 4 m and 5 m.

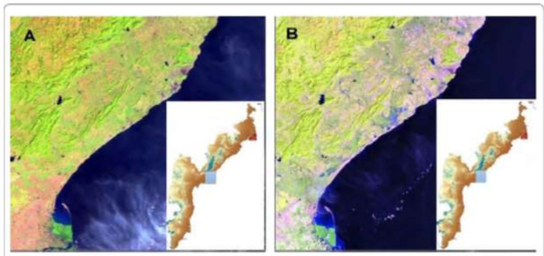


**Figure 7:** Inundation scenario of Visakhapatnam area for sea level rise A) Nov, 1977 (Landsat MSS) B) Nov, 2005 (Landsat TM) with true colour composition.

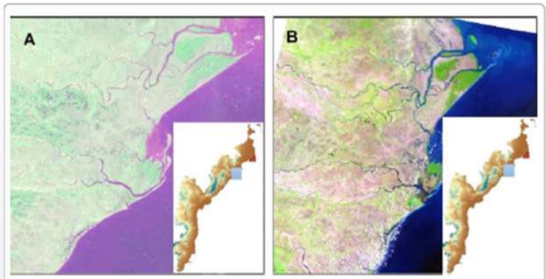
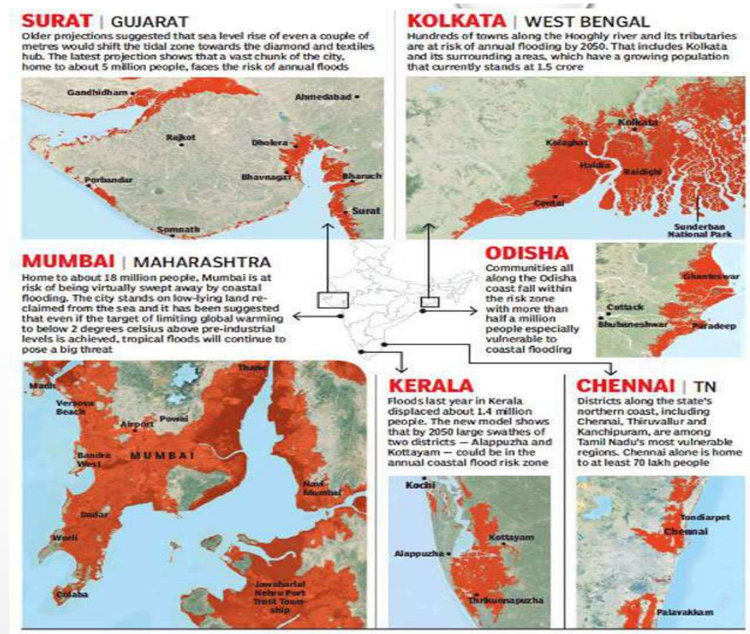


**Figure 8:** Inundation scenario of Paradeep area for sea level rise A) Nov, 1977 (Landsat MSS) B) Nov, 2005 (Landsat TM) with true colour composition.



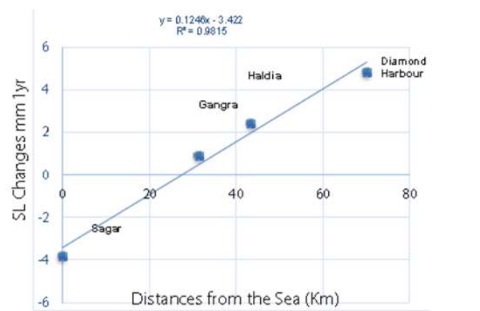
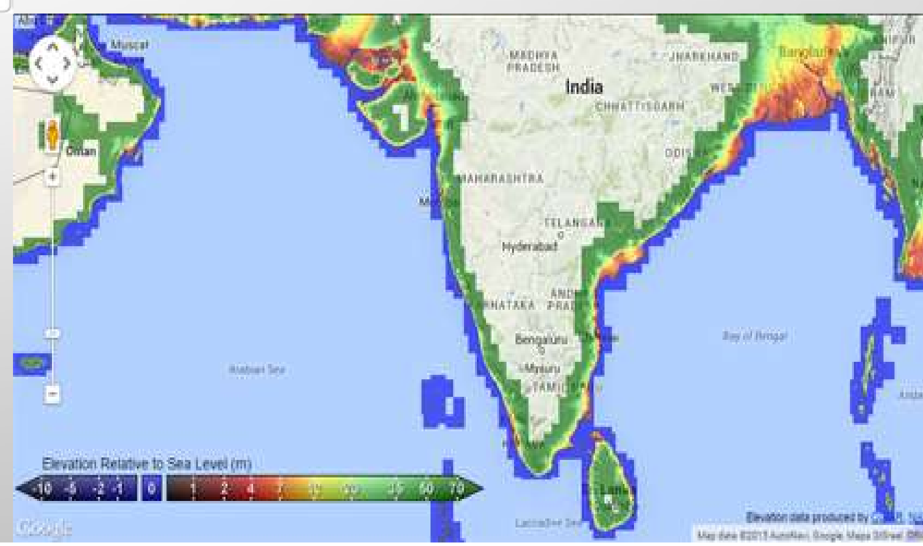




**Figure 11:** The relationship between sea level changes and distance from the sea in most vulnerable coastal area of West Bengal.




| Sea level rise trends (mm/year) | Location (station wise adjoining area) | Elevation from mean sea level(m) (fig. no. 11) | Slope (in degree) | Inundation level and erosion | Tidal amplitude (m) | Vulnerability and risk zone |
|---|---|---|---|---|---|---|
| Below 0.5 | Bhubaneswar and Chennai | Up to 200 m | 0.10 | medium | 40-120 | high |
| 0.5 – 1.0 | Visakhapatnam | Up to 1000 m | 0.3 | medium | 60-85 | medium |
| Above 1.0 | Diamond Harbour | Up to 20 m | 0.05 | very high | 180 | very high |

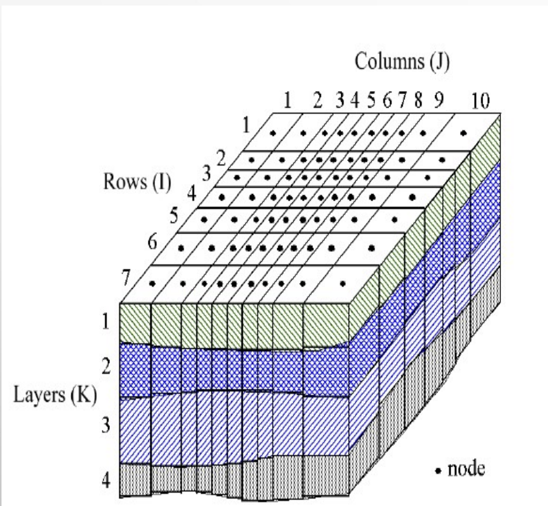
**Pramanik et al., 2015**

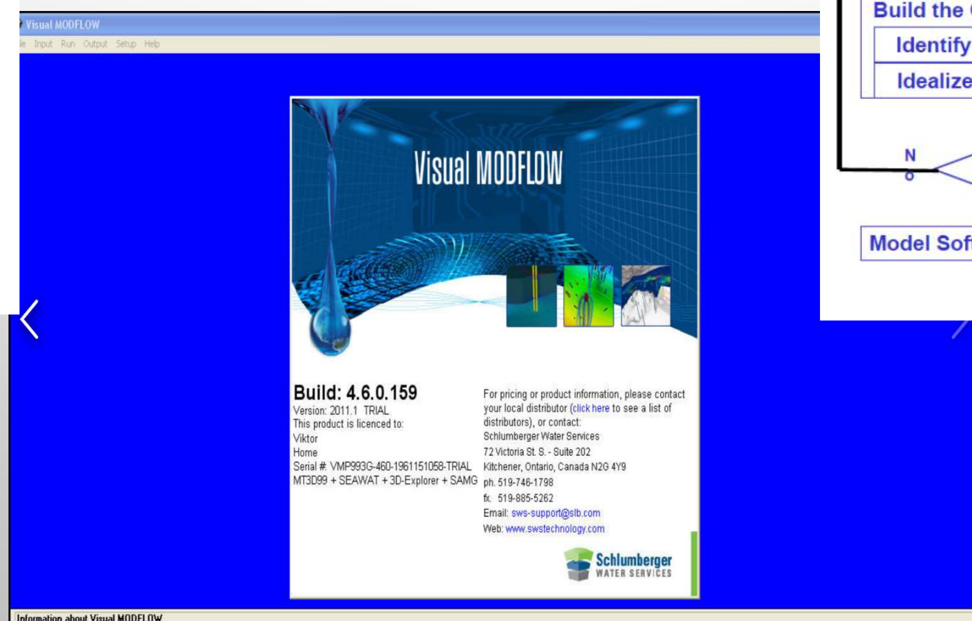
# Groundwater Flow modeling

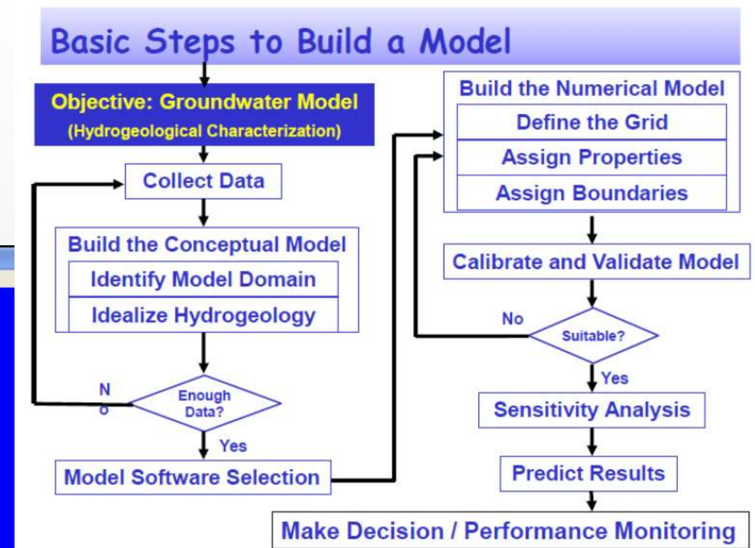
$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

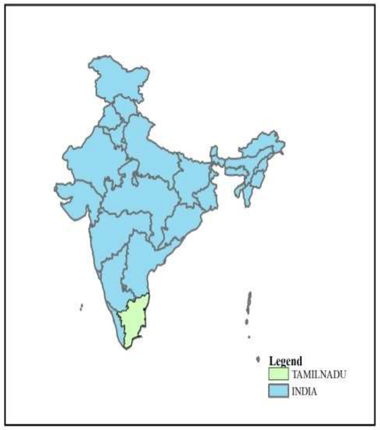
$$\nabla\cdot\rho K_f+\left(\nabla_{h_f}+\frac{(\rho-\rho_f)}{\rho_f}\nabla_z\right)=\rho S_f\frac{\partial h_f}{\partial t}+n\frac{\partial\rho}{\partial C}\frac{\partial C}{\partial t}-\overline{\rho q}$$

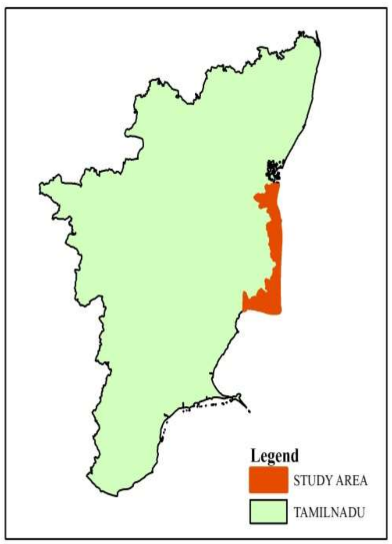
**$K_{xx}$, $K_{yy}$ and $K_{zz}$ are hydraulic conductivity along x,y, z Directions (L/T), h - is Potentiometric head (L), w - is volumetric flux per unit volume representing sources or sinks of water, Ss - is the specific storage of the porous material ($L^{-1}$) , t - is time (T), P i s fluid density ($ML^{-3}$). Kf fresh water hydraulic conductivity ($LT^{-1}$), Hf equivalent fresh water head (L). Pf is the density of fresh water ($ML^{-3}$), Sf equivalent fresh water storage, coefficient ($L^{-1}$), tis time (T), N is porosity (L0), C concentration of dissolved constituent (salinity, Cl) ($ML^{-3}$), ρ fluid density of source or a sink ($ML^{-3}$, q is the flow rate of the source or sink ($T^{-1}$).**

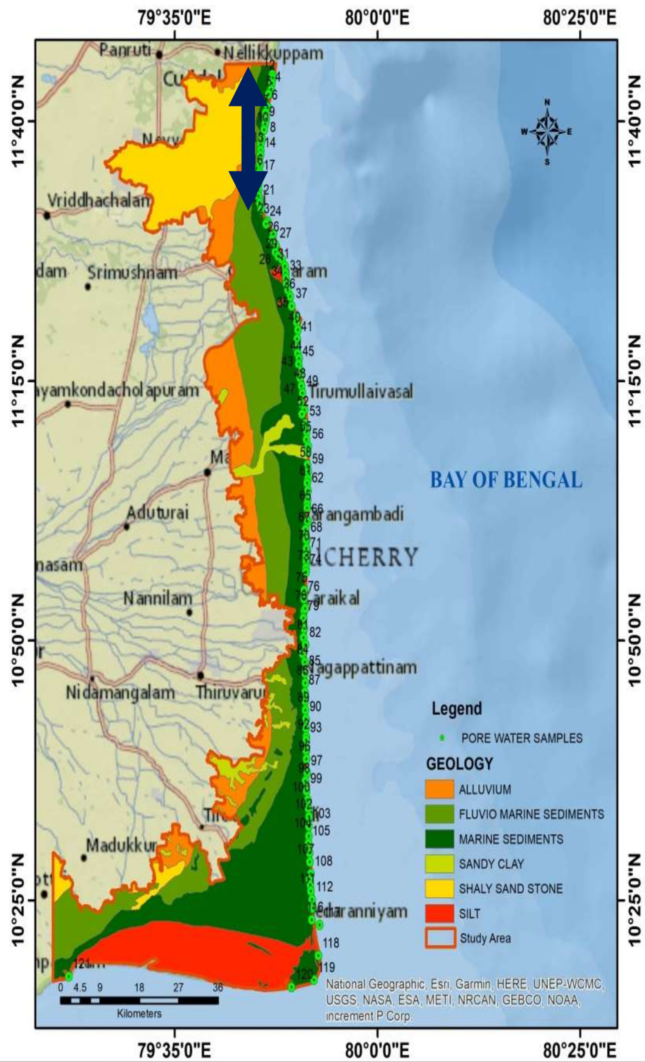




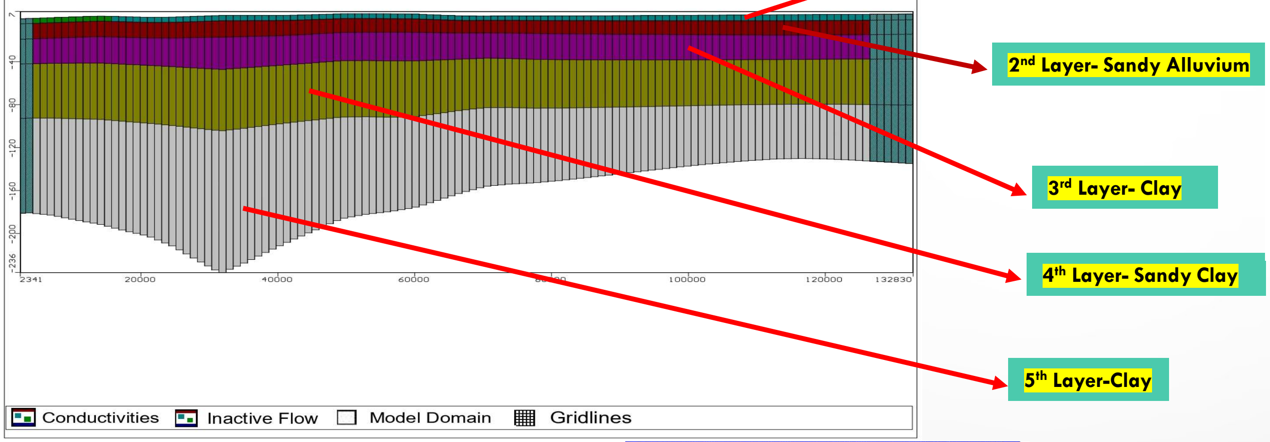




| Epoch | Stage/formation | Lithology |
|---|---|---|
| Recent Pleistocene | Quaternary | Soils, Alluvium and beach sand, boulder conglomerate, Older alluvium and laterite |
| Pliocene | Karaikal beds | Sand and clay with fossils |
| Miocene | Cuddalore sandstone<br>Niniyur<br>Ariyalur | Mottled and friable sandstone, buff coloured, clay and gravel Arenaceous limestone and sandstone and clay |
| Cretaceous to Upper Carboniferous | Tiruchirappalli<br>Uttatur<br>Satyavedu<br>Sriperumbudur | Sandstone, clay and shell limestone Basal limestone, coral clay and sandy bed Ferruginous sandstone and conglomerate Clay, shale and feldspathic sandstone |
| Unconformity | | |
| Archaean | | Gneissic complex, charnockite, granite and associated basic and ultra-basic intrusive |

- Total coastal stretch-200 km
- Annual Normal Rainfall -1000 to 1500 mm.

# Groundwater Dynamics



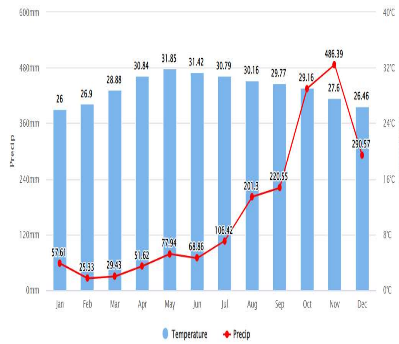
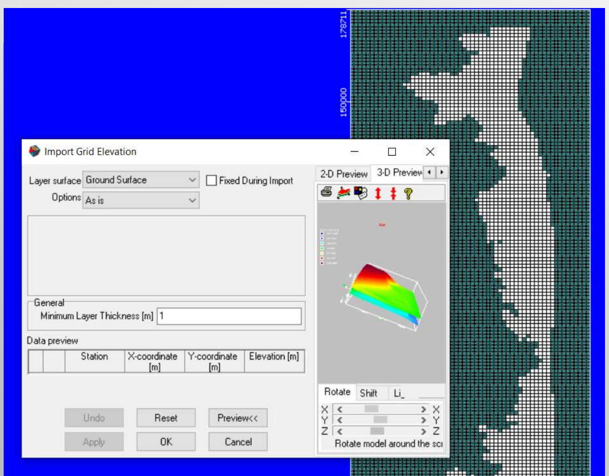
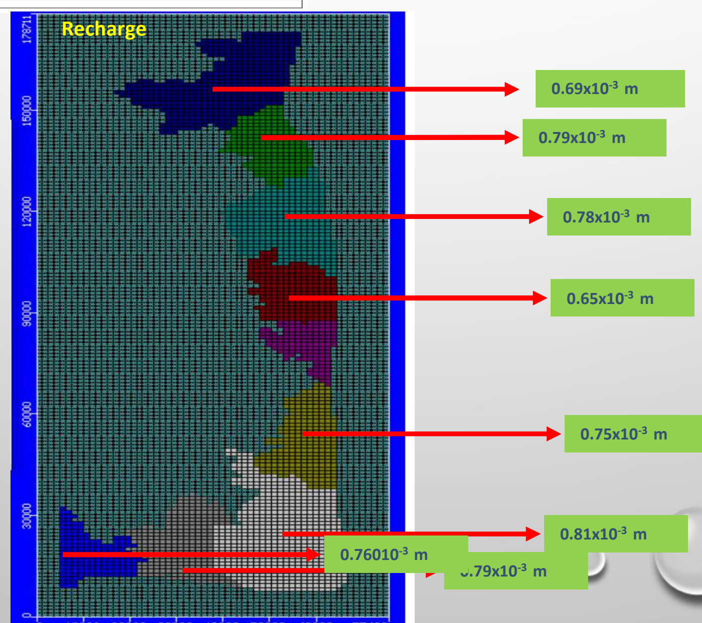



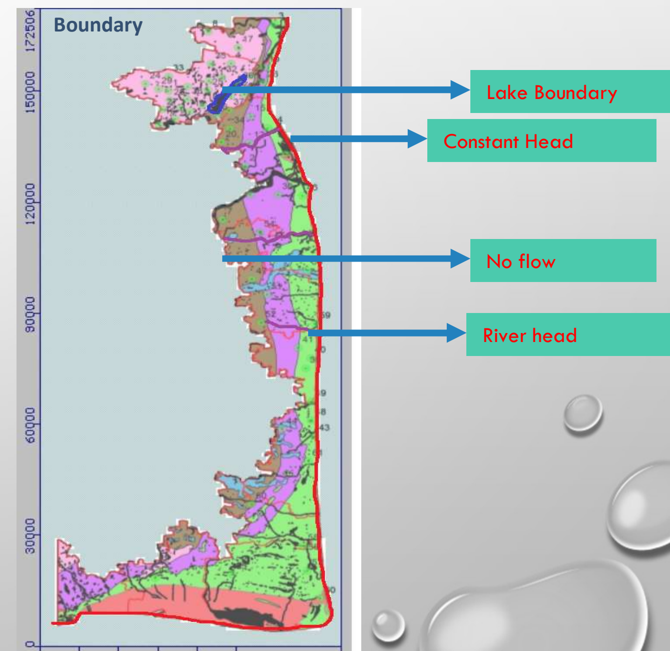

Table 4. NORMS FOR RAINFALL INFILTRATION FACTOR AS RECOMMENDED BY GEC 1997

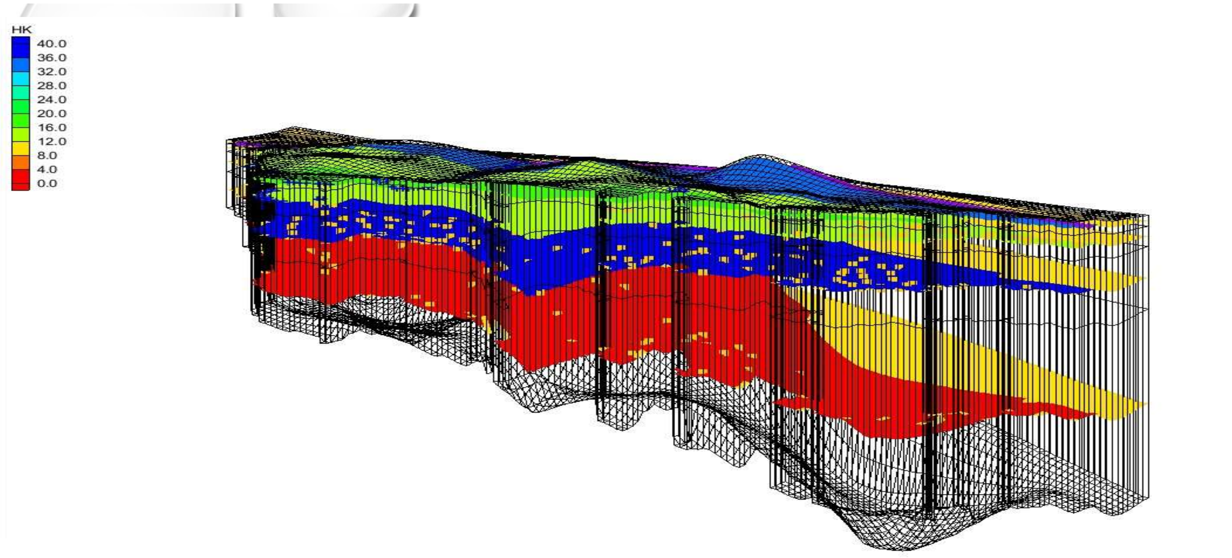
| S.No | Formation | Recommended Value (%) | Minimum Value (%) | Maximum Value (%) |
|---|---|---|---|---|
| (a) | Alluvial areas | | | |
| | Indo-Gangetic and inland areas | 22 | 20 | 25 |
| | East coast | 16 | 14 | 18 |
| | West coast | 10 | 8 | 12 |
| (b) | Hard rock areas | | | |
| | Weathered granite, gneiss and schist with low clay content | 11 | 10 | 12 |
| | Weathered granite, gneiss and schist with significant clay content | 8 | 5 | 9 |
| | Granulite facies like charnockite etc. | 5 | 4 | 6 |
| | Vesicular and jointed basalt | 13 | 12 | 14 |
| | Weathered basalt | 7 | 6 | 8 |
| | Laterite | 7 | 6 | 8 |
| | Semi-consolidated sandstone | 12 | 10 | 14 |
| | Consolidated sandstone, quartzite ,limestone (except cavernous limestone) | 6 | 5 | 7 |
| | Phyllites, shales | 4 | 3 | 5 |
| | Massive poorly fractured rock | 1 | 1 | 3 |



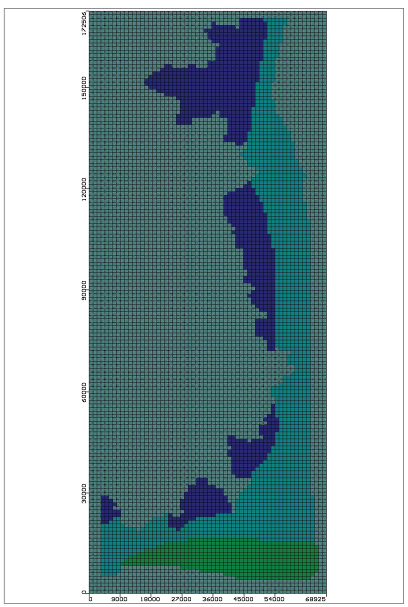

| | | | | | | |
|---|---|---|---|---|---|---|
| Max | 119 | 111.2 | 96.4 | 76.2 | 34.3 | -14.8 |
| Min | -1 | -9.1 | -27.3 | -62.7 | -127.6 | -332.8 |
| Avg | 11.12 | 6.444 | -6.936 | -29.324 | -73.734 | -140.354 |

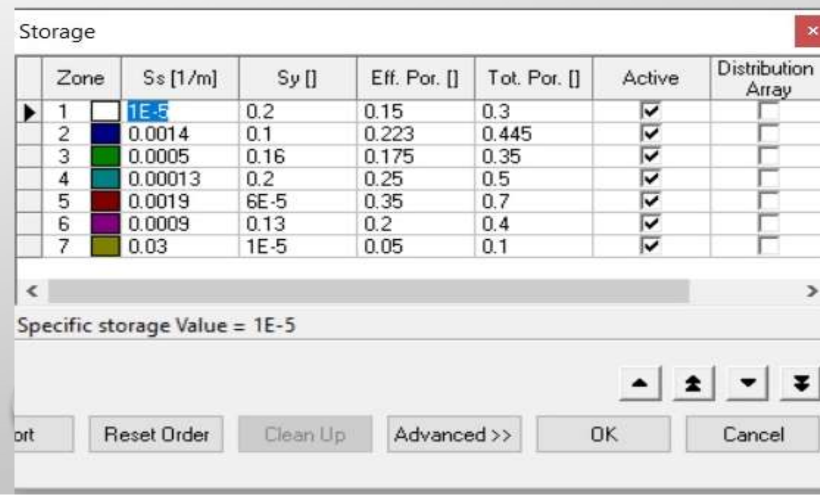





| Aquifer Parameters | 1st Layer | | | 2nd Layer | 3rd Layer | 4th Layer | 5th Layer |
|---|---|---|---|---|---|---|---|
| | Alluvium | Marine Sediments | Silt | Sandy Alluvium | Clay | Sandy Clay | Clay |
| Conductivity (m/d) | 35 | 2.6 | 0.51 | 15.206 | 0.112 | 0.19 | 0.112 |
| Specific storage (Ss) m/d | 0.0005 | 0.0005 | 0.0014 | 0.00013 | 0.0019 | 0.00128 | 0.0019 |
| Specific yield (Sy) m/d | 0.16 | 0.16 | 0.1 | 0.2 | 0.03 | 0.07 | 0.03 |
| Total Porasity % | 0.35 | 0.35 | 0.445 | 0.5 | 0.7 | 0.38 | 0.7 |
| Effective Porosity % | 0.175 | 0.175 | 0.2225 | 0.25 | 0.35 | 0.19 | 0.35 |
| | | | | | | | |
| * In fist layer alluvium and marine sediments has been considered as same, as alluvium | | | | | | | |

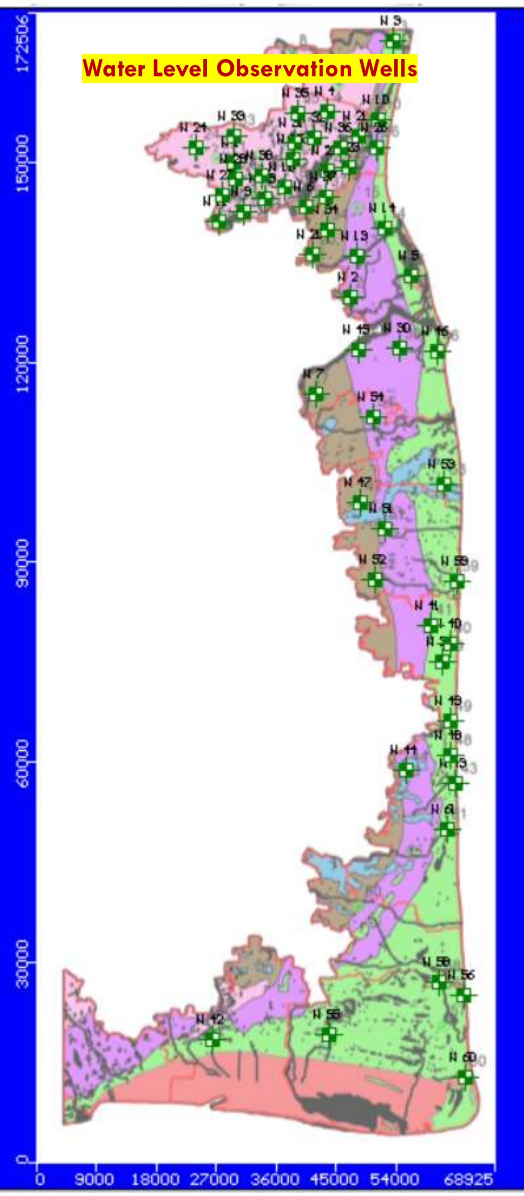



Storage

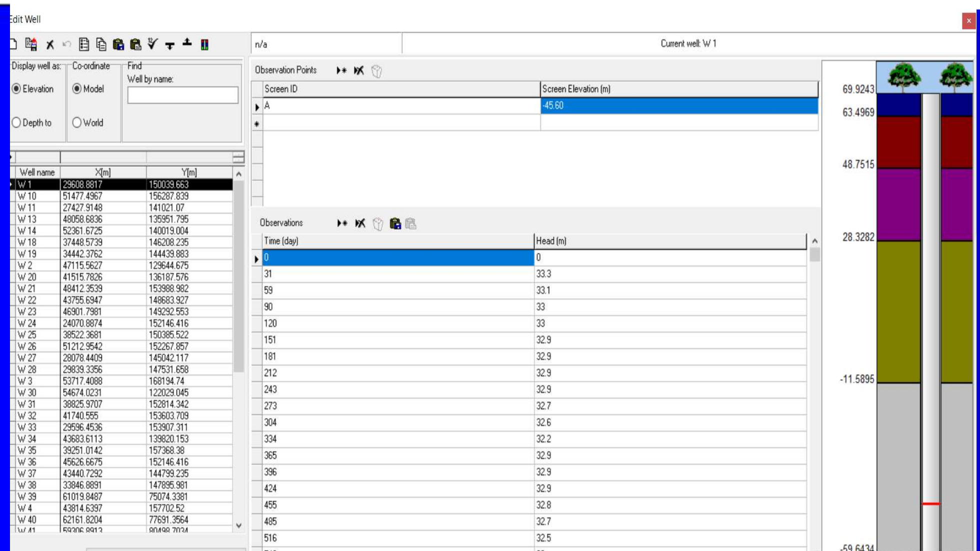
| Zone | Ss [1/m] | Sy [] | Eff. Por. [] | Tot. Por. [] | Active | Distribution Array |
|---|---|---|---|---|---|---|
| 1 | 1E-5 | 0.2 | 0.15 | 0.3 | ☑ | ☐ |
| 2 | 0.0014 | 0.1 | 0.223 | 0.445 | ☑ | ☐ |
| 3 | 0.0005 | 0.16 | 0.175 | 0.35 | ☑ | ☐ |
| 4 | 0.00013 | 0.2 | 0.25 | 0.5 | ☑ | ☐ |
| 5 | 0.0019 | 6E-5 | 0.35 | 0.7 | ☑ | ☐ |
| 6 | 0.0009 | 0.13 | 0.2 | 0.4 | ☑ | ☐ |
| 7 | 0.03 | 1E-5 | 0.05 | 0.1 | ☑ | ☐ |

Specific storage Value = 1E-5

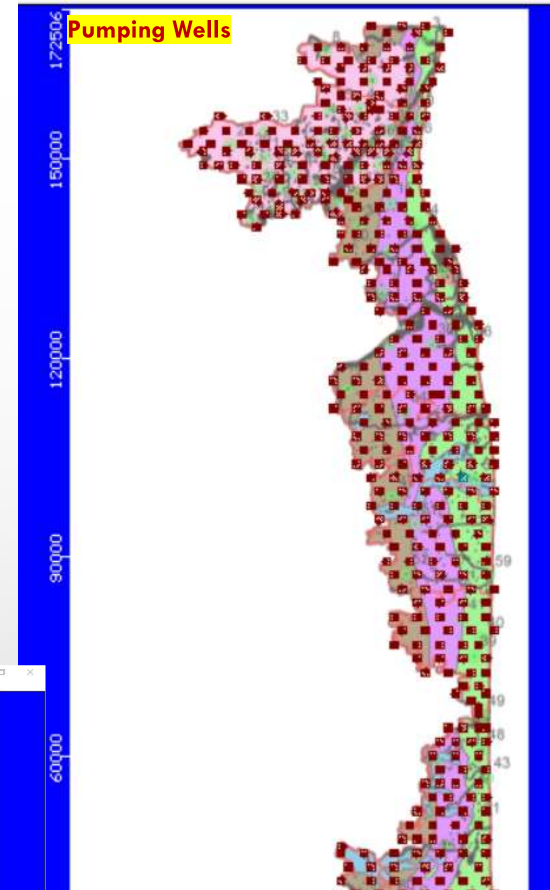
ort | Reset Order | Clean Up | Advanced >> | OK | Cancel



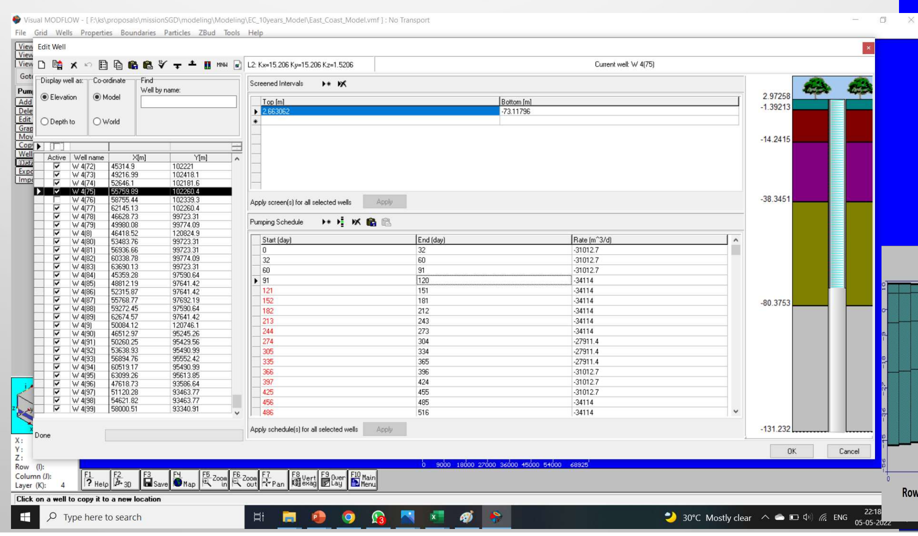
Water Level Observation Wells

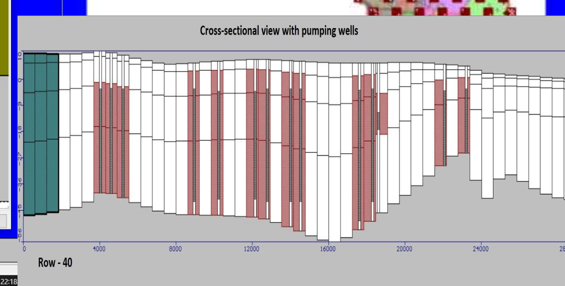
Edit Well
Current well: W 1
Observation Points
Observations

Pumping Wells

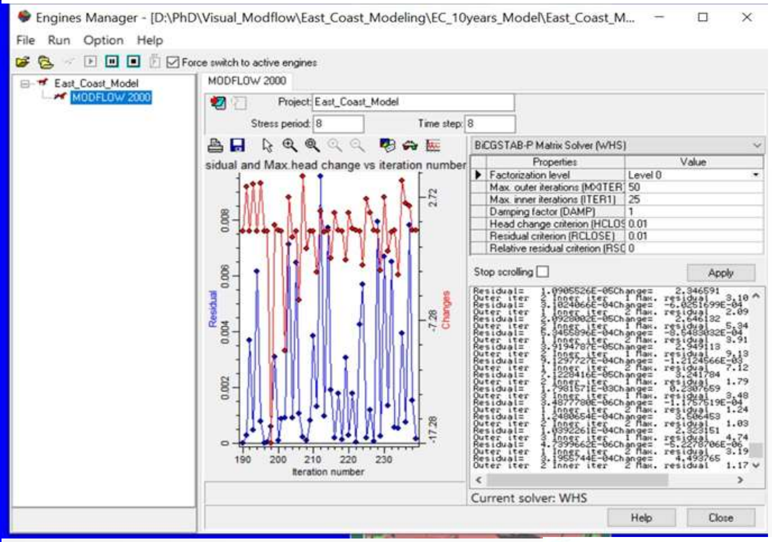



Edit Well
Current well: W 4(75)
Screened Intervals
Pumping Schedule

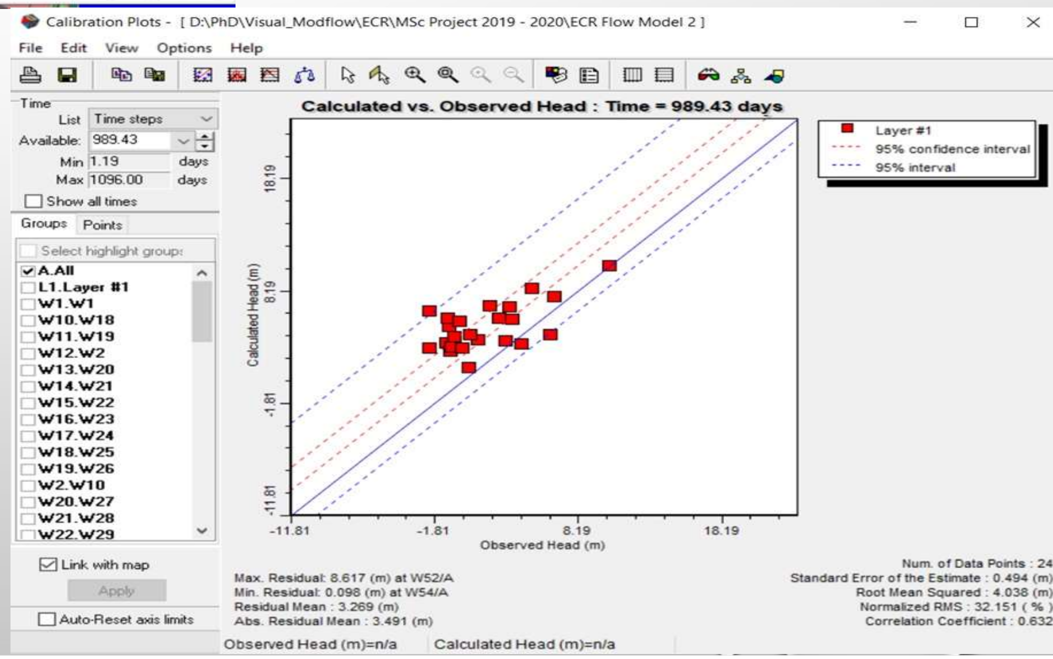



Cross-sectional view with pumping wells
Row - 40

Engines to Run
Engine
Run
MODFLOW 2000
MODPATH
ZoneBudget
MT3DMS
PEST
Translate & Run
Translate
Run
Cancel
Advanced >>
Auto-start engines

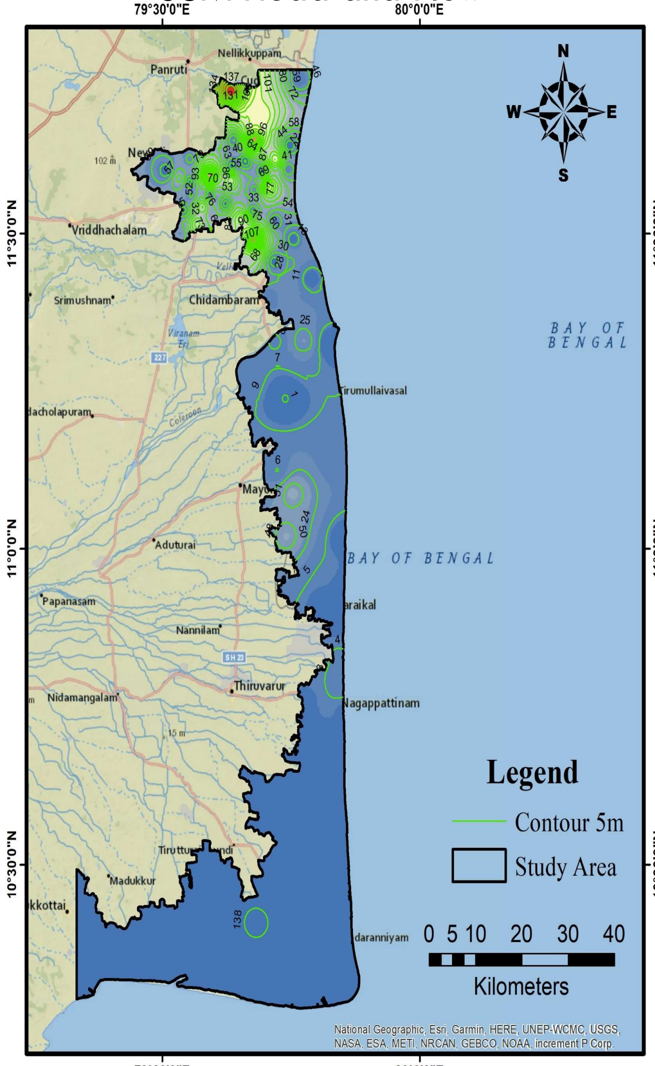



Engines Manager - [D:\PhD\Visual_Modflow\East_Coast_Modeling\EC_10years_Model\East_Coast_M...
File Run Option Help
Force switch to active engines
East_Coast_Model
MODFLOW 2000
Project: East_Coast_Model
Stress period: 8
Time step: 8
BiCGSTAB-P Matrix Solver (WHS)
Properties
Value
Factorization level
Level 0
Max. outer iterations (MXITER)
50
Max. inner iterations (ITER1)
25
Damping factor (DAMP)
1
Head change criterion (HCLOSE)
0.01
Residual criterion (RCLOSE)
0.01
Relative residual criterion (RSC
0
Stop scrolling
Apply
Residual
Changes
Iteration number
Current solver: WHS
Help
Close

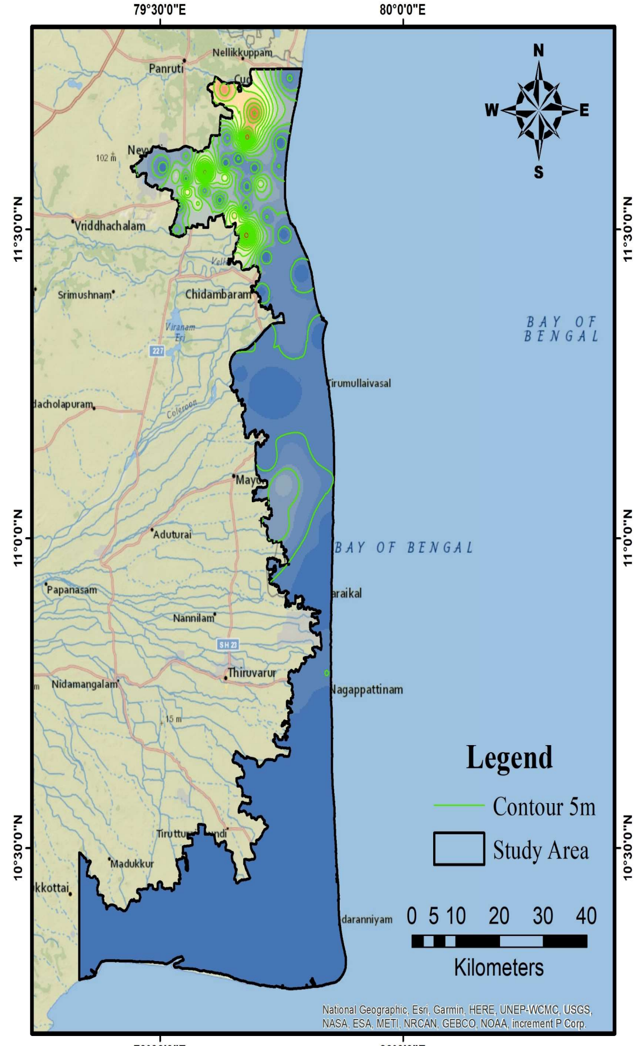



Calibration Plots - [ D:\PhD\Visual_Modflow\ECR\MSc Project 2019 - 2020\ECR Flow Model 2 ]
File Edit View Options Help
Time
List Time steps
Available: 989.43
Min 1.19 days
Max 1096.00 days
Show all times
Groups Points
Select highlight group:
A.All
L1.Layer #1
W1.W1
W10.W18
W11.W19
W12.W2
W13.W20
W14.W21
W15.W22
W16.W23
W17.W24
W18.W25
W19.W26
W2.W10
W20.W27
W21.W28
W22.W29
Link with map
Apply
Auto-Reset axis limits
Calculated vs. Observed Head : Time = 989.43 days
Layer #1
95% confidence interval
95% interval
Calculated Head (m)
Observed Head (m)
-11.81
-1.81
8.19
18.19
Num. of Data Points : 24
Standard Error of the Estimate : 0.494 (m)
Root Mean Squared : 4.038 (m)
Normalized RMS : 32.151 ( % )
Correlation Coefficient : 0.632
Max. Residual: 8.617 (m) at W52/A
Min. Residual: 0.098 (m) at W54/A
Residual Mean : 3.269 (m)
Abs. Residual Mean : 3.491 (m)
Observed Head (m)=n/a
Calculated Head (m)=n/a

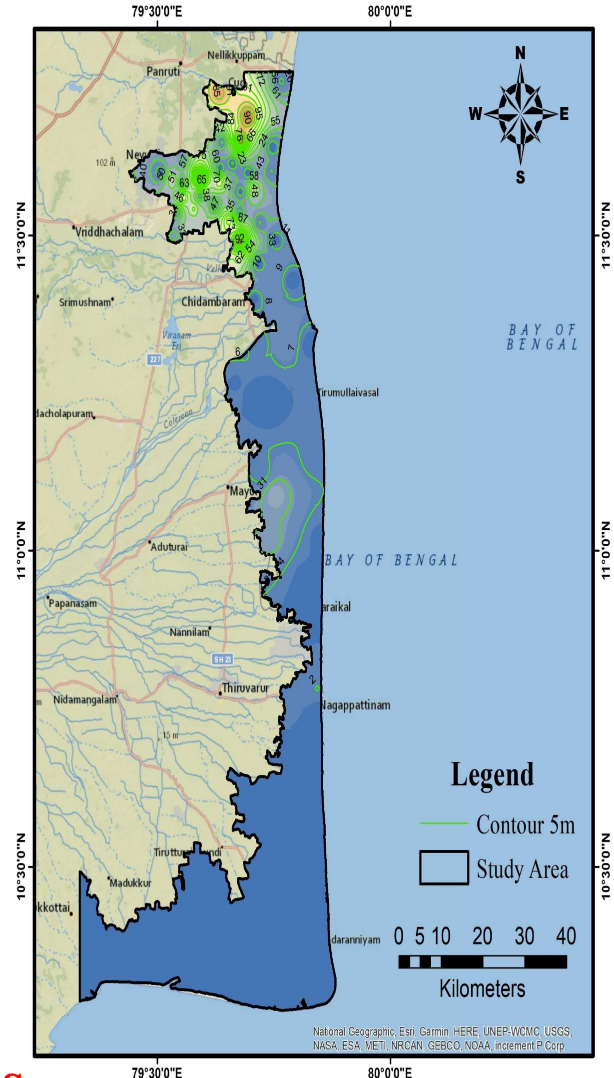
SUM Head and Flow



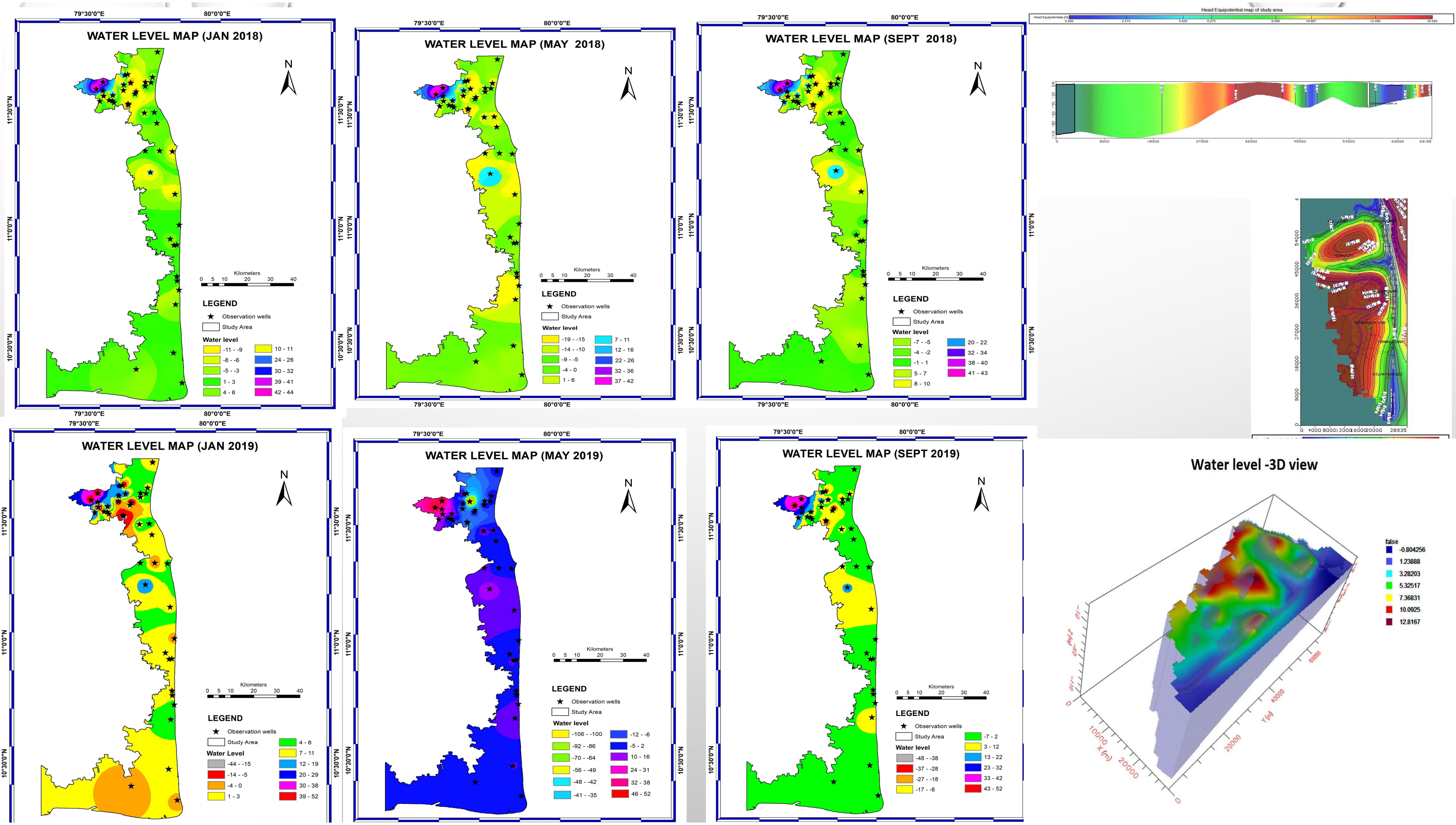

MON Head and Flow

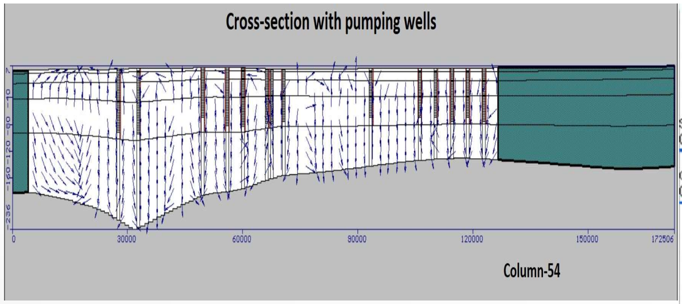


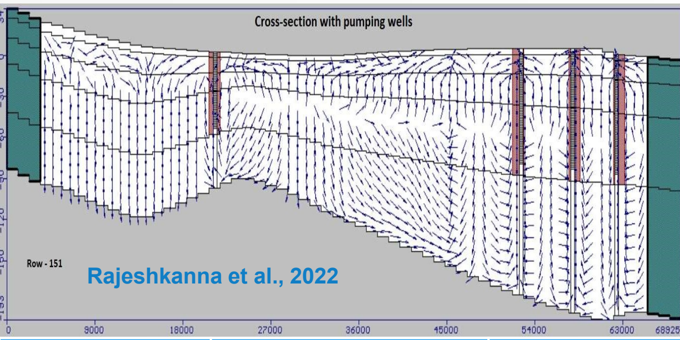

POM Head and Flow

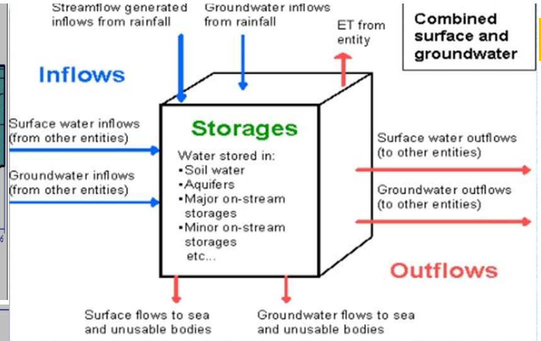



**Water Level variations for 3 stress periods**

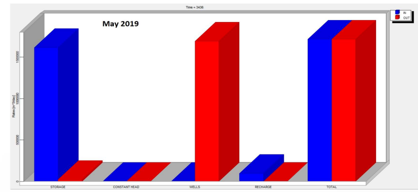

WATER LEVEL MAP (JAN 2018)
WATER LEVEL MAP (MAY 2018)
WATER LEVEL MAP (SEPT 2018)
WATER LEVEL MAP (JAN 2019)
WATER LEVEL MAP (MAY 2019)
WATER LEVEL MAP (SEPT 2019)
79°30'0"E
80°0'0"E
11°30'0"N
11°0'0"N
10°30'0"N
N
Kilometers
0 5 10 20 30 40
LEGEND
Observation wells
Study Area
Water level
-11 - -9
-8 - -6
-5 - -3
1 - 3
4 - 6
10 - 11
24 - 26
30 - 32
39 - 41
42 - 44
-19 - -15
-14 - -10
-9 - -5
-4 - 0
1 - 6
7 - 11
12 - 16
22 - 26
32 - 36
37 - 42
-7 - -5
-4 - -2
-1 - 1
5 - 7
8 - 10
20 - 22
32 - 34
38 - 40
41 - 43
Water Level
-44 - -15
-14 - -5
-4 - 0
1 - 3
4 - 6
7 - 11
12 - 19
20 - 29
30 - 38
39 - 52
-106 - -100
-92 - -86
-70 - -64
-56 - -49
-48 - -42
-41 - -35
-12 - -6
-5 - 2
10 - 16
24 - 31
32 - 38
46 - 52
-48 - -38
-37 - -28
-27 - -18
-17 - -8
-7 - 2
3 - 12
13 - 22
23 - 32
33 - 42
43 - 52
Head Equipotential map of study area
Water level -3D view
false
-0.804256
1.23888
3.28203
5.32517
7.36831
10.0925
12.8167
X (m)
Y (m)
Z (m)
10000
20000
40000
60000

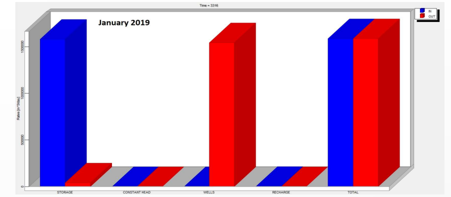


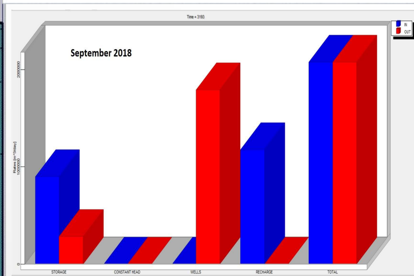



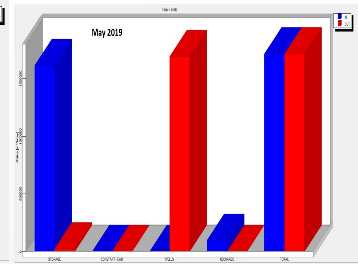



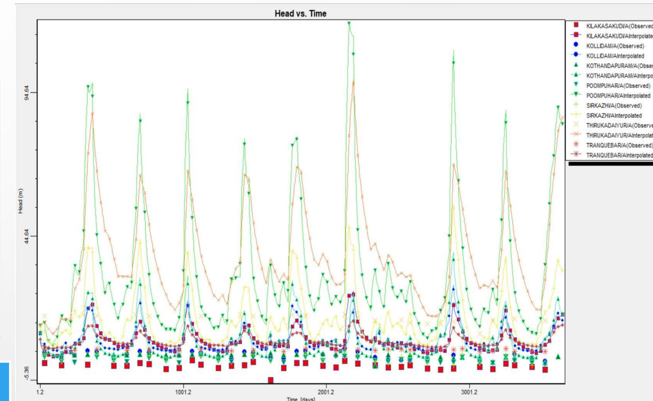

$$(P + GW_{in}) - (E + T + I + GW_{out} + Q) = \Delta Storage_{reservoir}$$



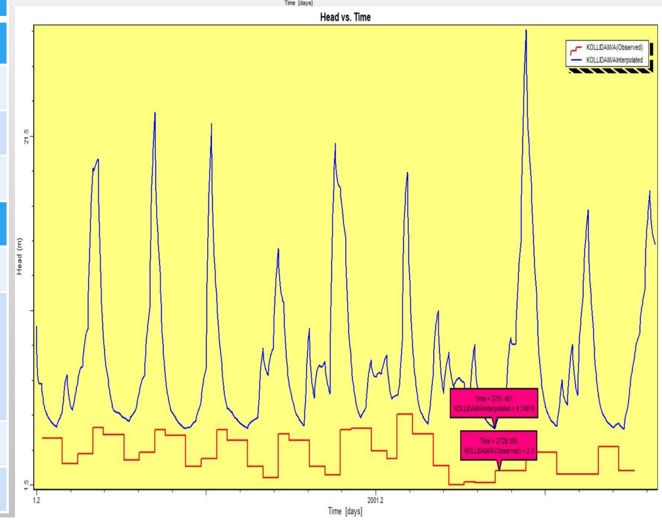



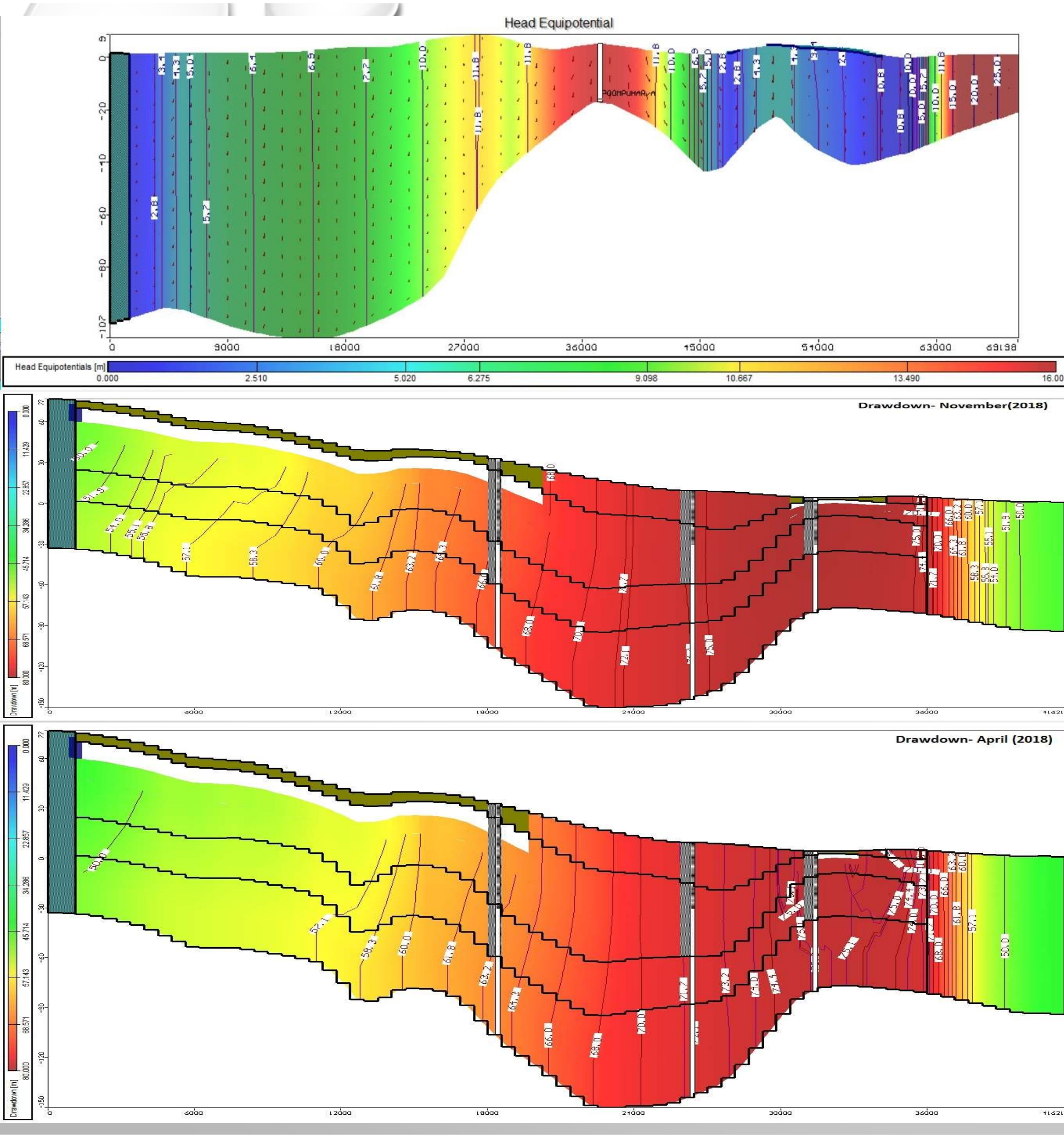



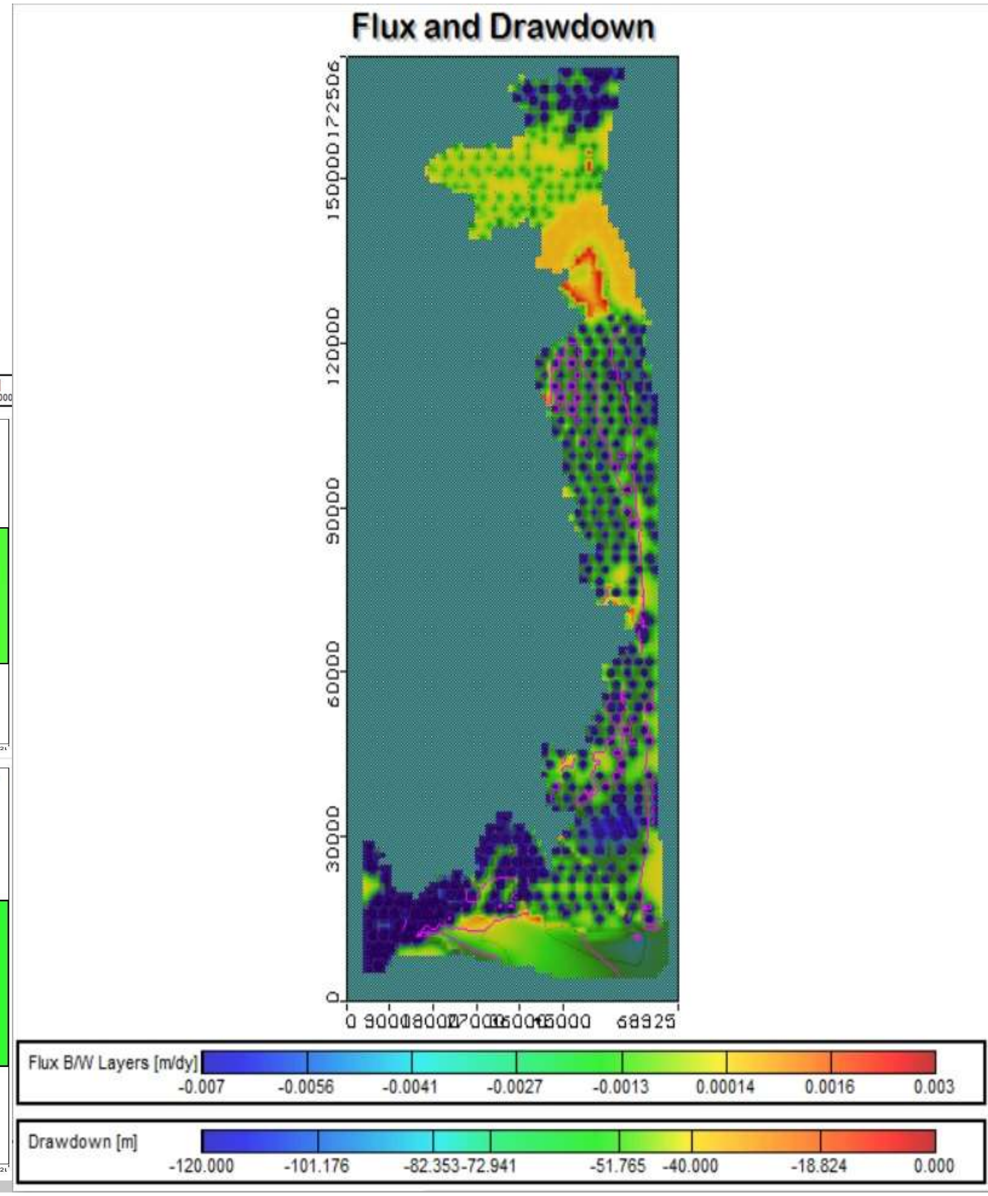



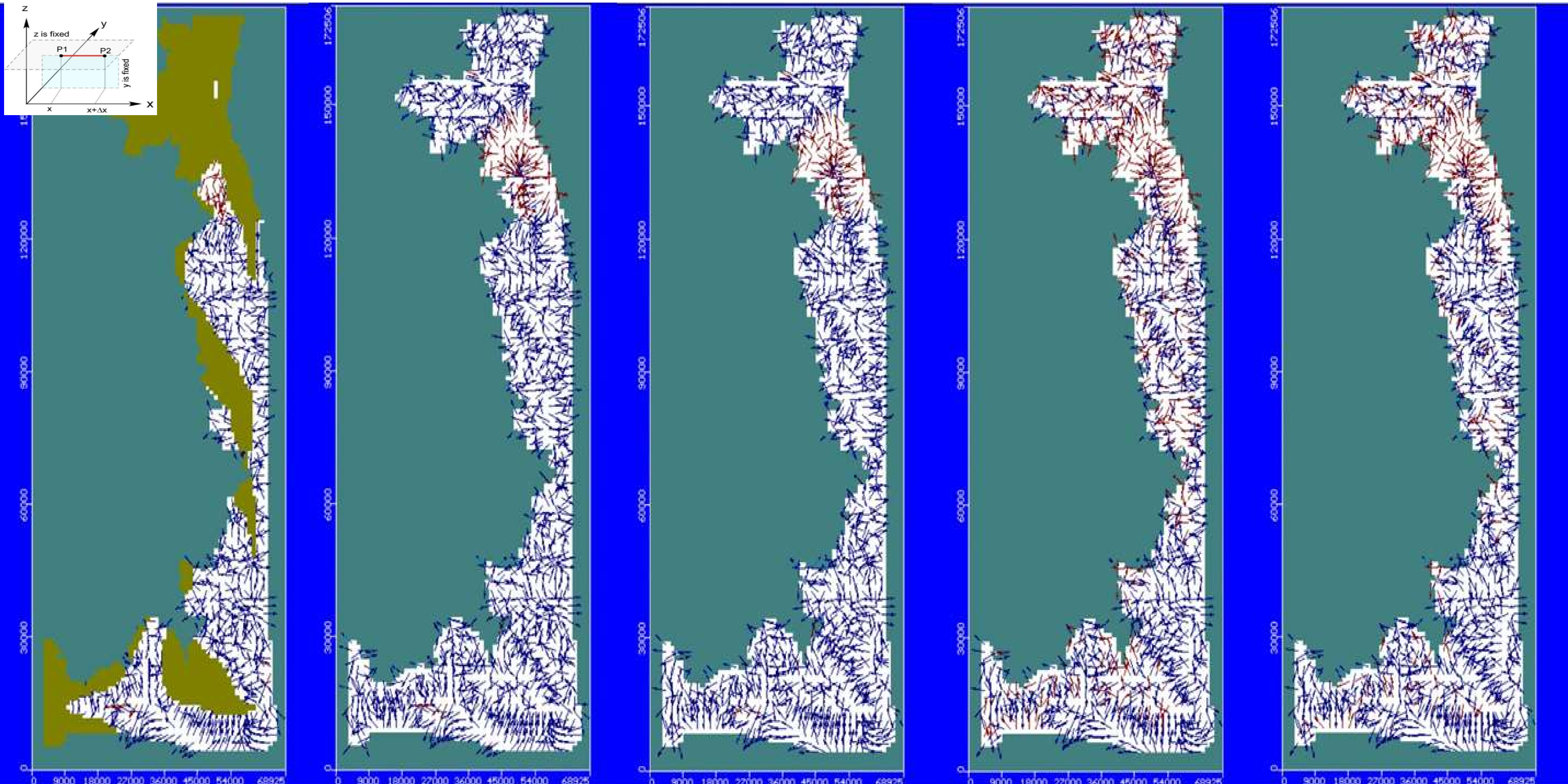




| Component | 2018 Sept ($m^3$/day) | 2019 Jan ($m^3$/day) | 2019 May ($m^3$/day) | 2019 Sep ($m^3$/day) |
|---|---|---|---|---|
| **Inflow** | | | | |
| Storage | 899560 | 1581400 | 1615000 | 16424 |
| Recharge | 1174600 | 3194.7 | 98531 | 6397800 |
| Total | 2074200 | 1584600 | 1713500 | 6414300 |
| **Out flow** | | | | |
| Storage | 284700 | 41973 | 22146 | 4722900 |
| Groundwater Abstraction | 1789500 | 1542600 | 1691400 | 1691400 |
| Total | 2074200 | 1584600 | 1713500 | 6414300 |
| IN – OUT | -2.9798 | -5.1969 | -2.0539 | -5.5767 |

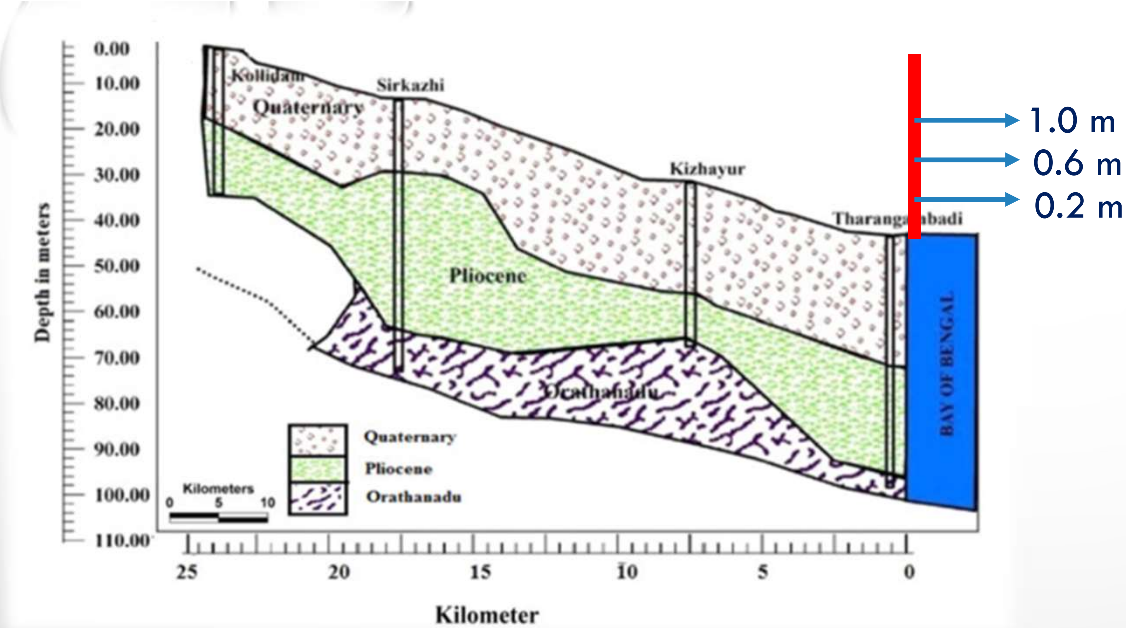


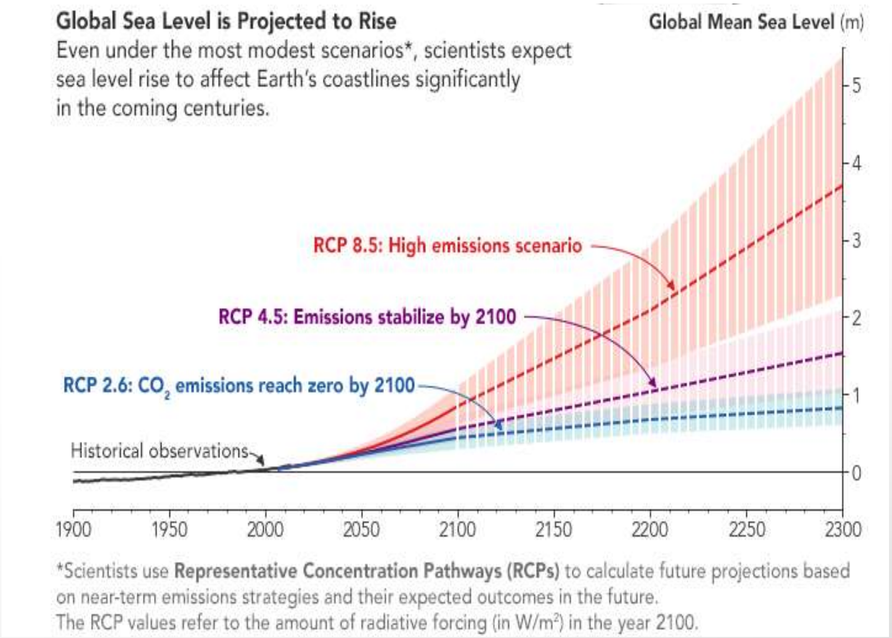

Head Equipotential
Head Equipotentials [m]
0.000
2.510
5.020
6.275
9.098
10.667
13.490
16.000
Drawdown- November(2018)
Drawdown- April (2018)


Flux and Drawdown
Flux B/W Layers [m/dy]
-0.007
-0.0056
-0.0041
-0.0027
-0.0013
0.00014
0.0016
0.003
Drawdown [m]
-120.000
-101.176
-82.353-72.941
-51.765
-40.000
-18.824
0.000

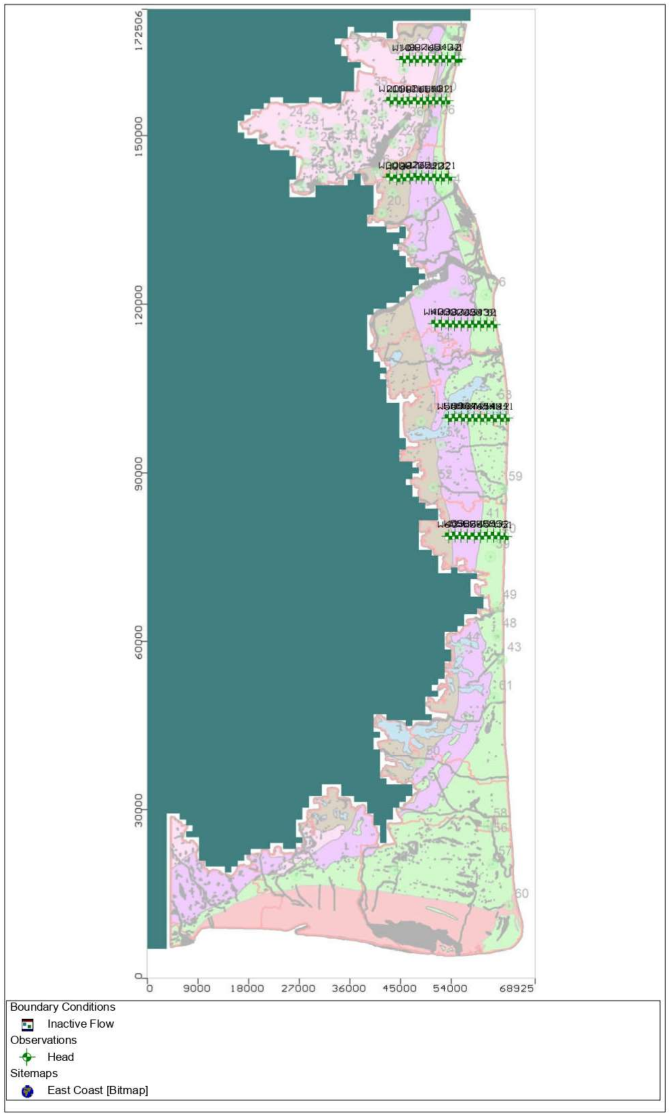


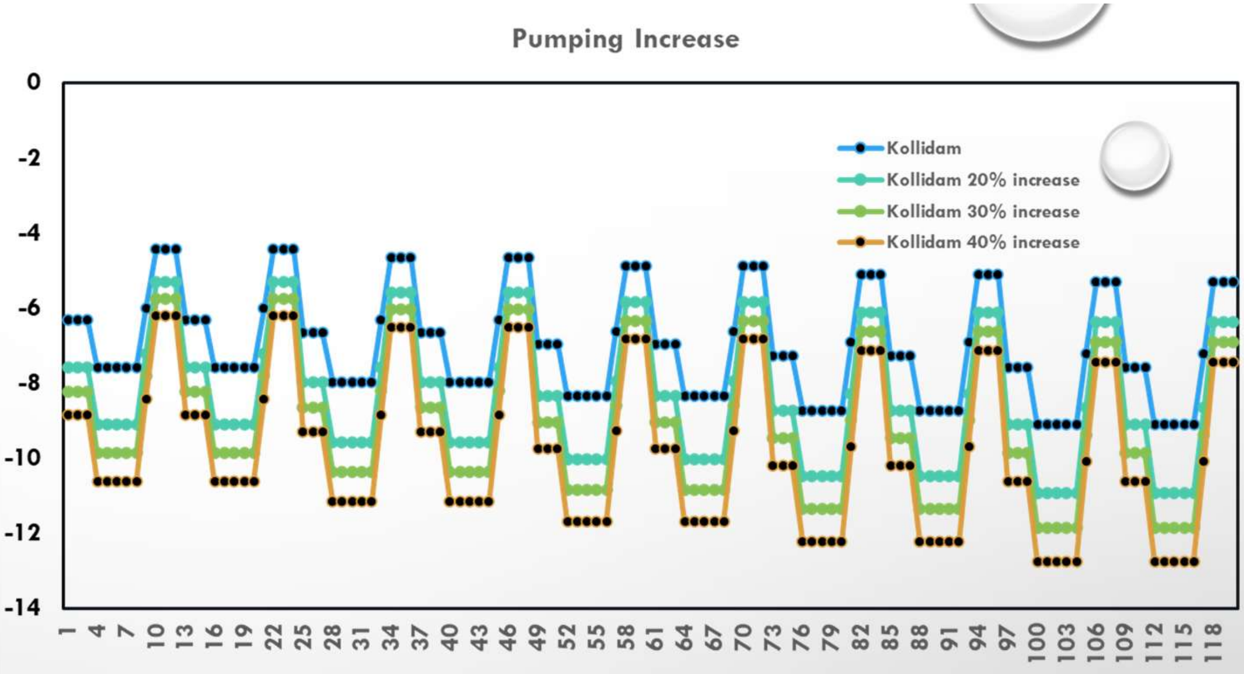
| 1st Layer | 2nd Layer | 3rd Layer | 4th Layer | 5th Layer |
| --- | --- | --- | --- | --- |
| 2.8 m/d | 2.5 m/d | 0.069 m/d | 0.03 m/d | 0.017 m/d |

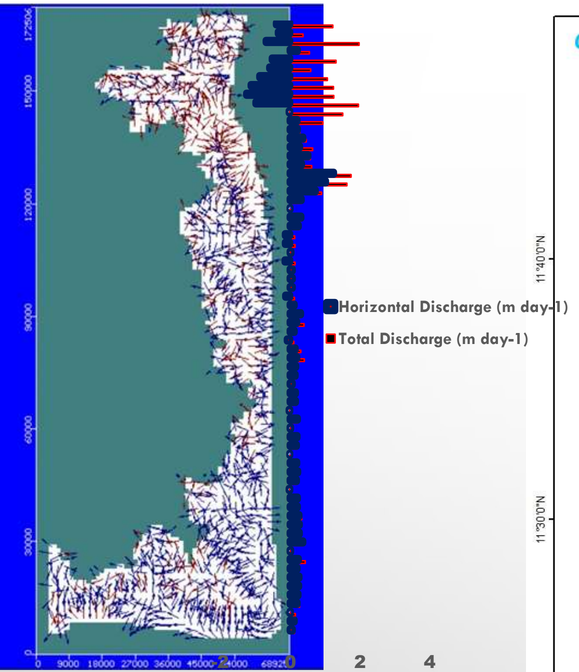


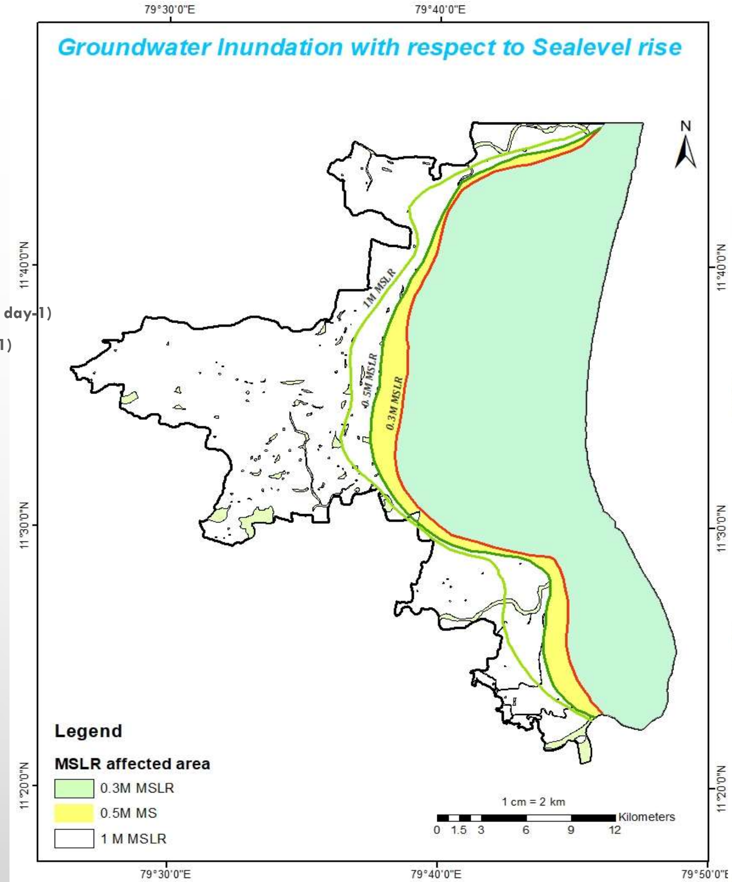



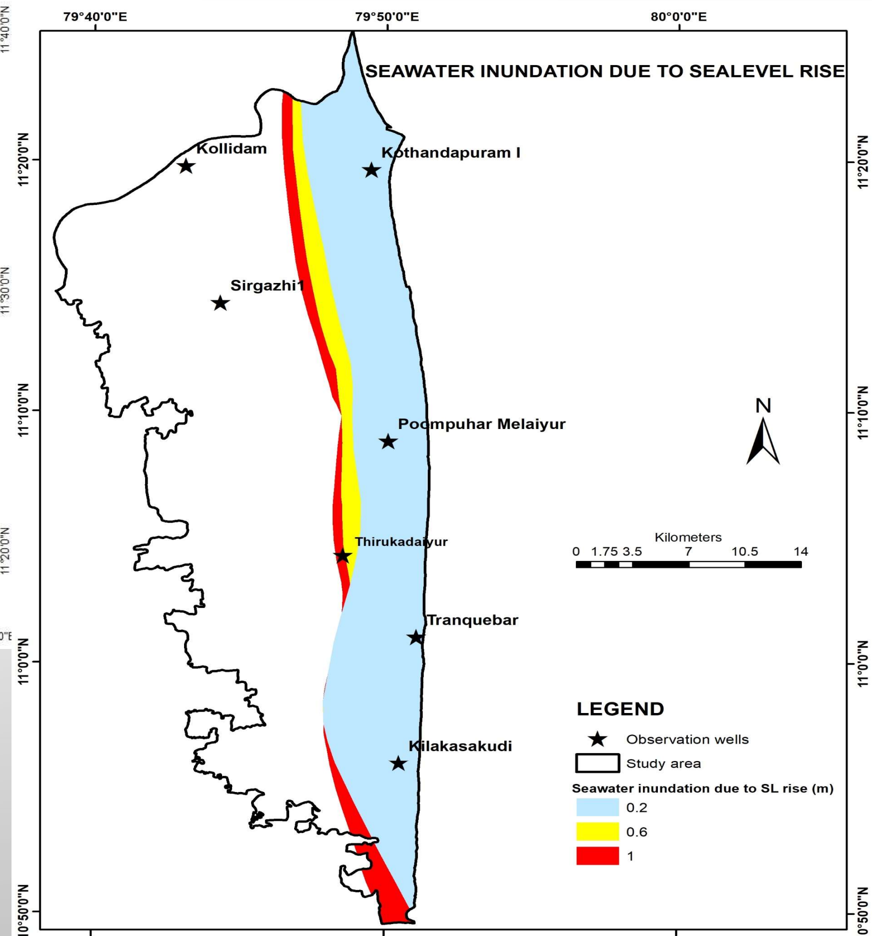

| SLR (m) (Cuddalore) | SLR(m) Nagapattinam) | Global scenarios (prediction) (NASA, 2021). |
|---|---|---|
| 0.2 | 0.2 | 2040 |
| 0.6 | 0.6 | 2080 |
| 1.0 | 1.0 | 2100 |


Boundary Conditions
Inactive Flow
Observations
Head
Sitemaps
East Coast [Bitmap]


Pumping Increase
Kollidam
Kollidam 20% increase
Kollidam 30% increase
Kollidam 40% increase

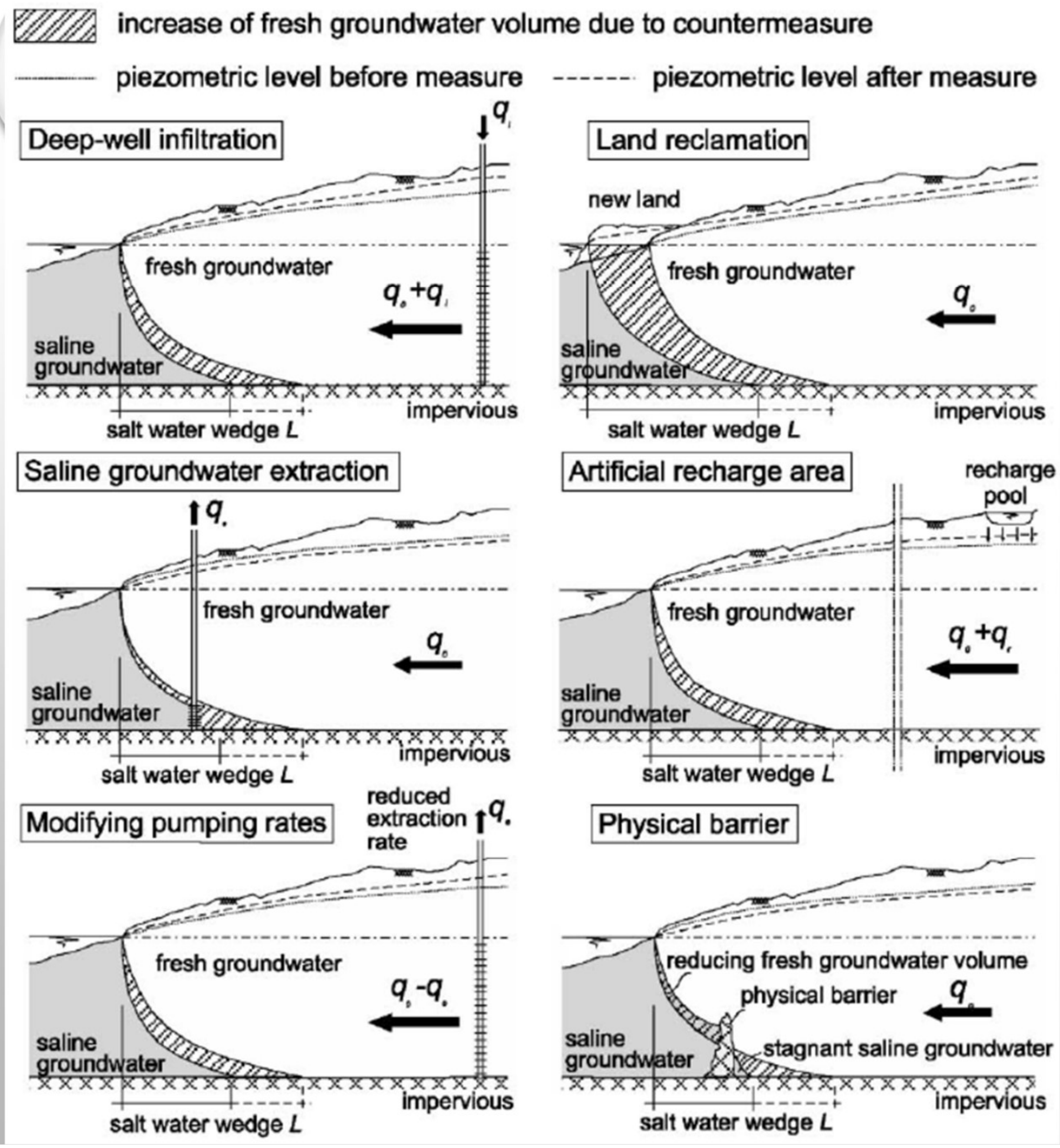

Horizontal Discharge (m day-1)
Total Discharge (m day-1)
0
2
4

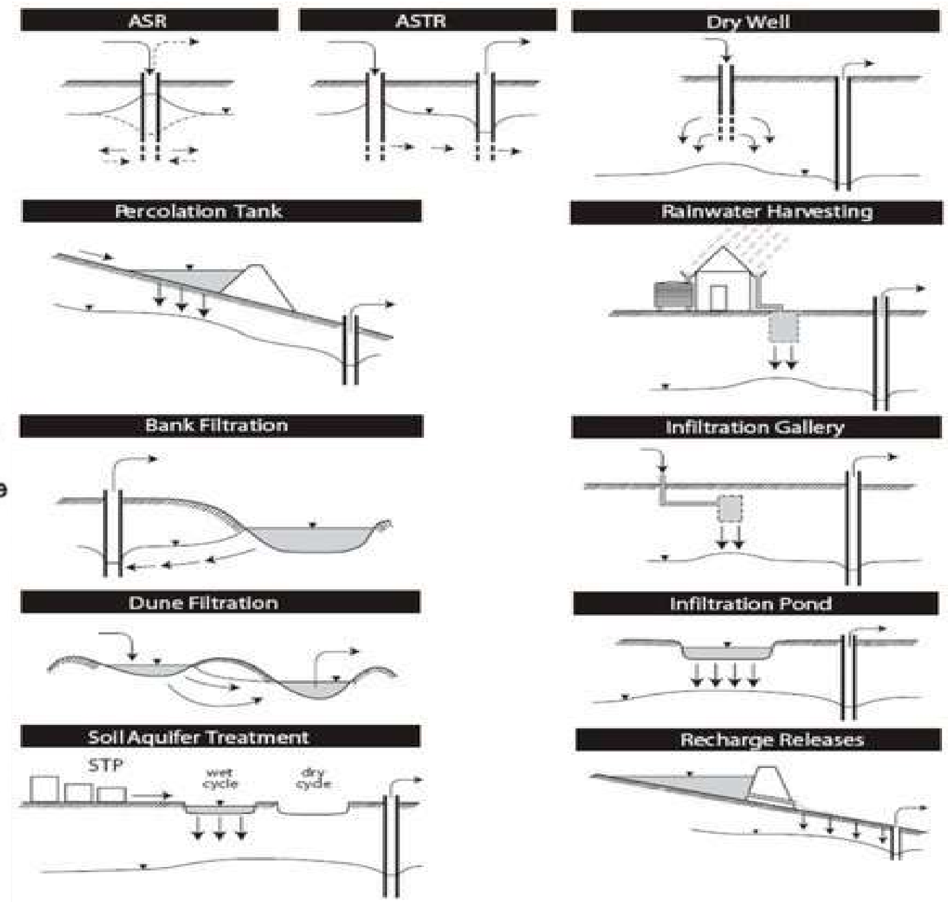

Groundwater Inundation with respect to Sealevel rise
79°30'0"E
79°40'0"E
79°50'0"E
11°40'0"N
11°30'0"N
11°20'0"N
N
1M MSLR
0.5M MSLR
0.3M MSLR
Legend
MSLR affected area
0.3M MSLR
0.5M MS
1 M MSLR
1 cm = 2 km
0 1.5 3 6 9 12
Kilometers


79°40'0"E
79°50'0"E
80°0'0"E
11°20'0"N
11°10'0"N
11°0'0"N
10°50'0"N
SEAWATER INUNDATION DUE TO SEALEVEL RISE
Kollidam
Kothandapuram I
Sirgazhi1
Poompuhar Melaiyur
Thirukadaiyur
Tranquebar
Kilakasakudi
N
Kilometers
0 1.75 3.5 7 10.5 14
LEGEND
Observation wells
Study area
Seawater inundation due to SL rise (m)
0.2
0.6
1

# UNCERTAINTIES

- Factors like tidal, wave, altitude and other factors influencing sea-level rise were not considered.
- Seawater intrusion was not reflected
- The initial head for sea level is the present sea level
- The study aims to highlight the combined impact of sea-level rise and pumping.
- The transient and steady-state for the initial model were calibrated, but the prediction models were not calibrated due to more significant uncertainties.




***ASR—Aquifer Storage and Recovery; ASTR—Aquifer Storage Transfer Recovery; STP—Sewerage Treatment Plant.***

**Source: Gualbert H. P. Oude Essink 2018; Dillon 2005**


HOW TO FIGHT
CLIMATE CHANGE
17 SUSTAINABILITY HACKS
WWW.THE-SHIFT.ORG
CONSERVE WATER
take a shower instead of a bath ■ water the garden, flush the toilet and wash the car with rainwater ■ use water saving shower head
EAT SMART
buy local and organic food ■ avoid packaging waste ■ save your left-overs for the next day ■ stop or reduce eating meat and fish
SAVE ENERGY
turn off turn the AC or central heating a bit lower ■ replace your old devices with energy-efficient ones ■ switch off devices when not in use
TRAVEL SUSTAINABLE
cover small distances by foot or bike ■ use public transport whenever possible ■ carpool ■ avoid air travel for all journeys less than 1000km ■ use The Shift's footprint calculator to plan your trip
USE CLEAN ENERGY
switch to a renewable energy supplier ■ participate in a local energy cooperative ■ install solar PV, solar thermal installation, or ground heat pump
BE AN EXAMPLE
Do not only change our own lifestyle but also help others reduce their ecological footprint. Together we make a difference!


THANK YOU


YOU CONTROL CLIMATE CHANGE.
TURN DOWN. SWITCH OFF. RECYCLE. WALK. CHANGE