Ground Water Hydrology

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Module No # 07
Lecture No # 34
Saline Water Intrusion in Aquifers Geochemical Investigations Control of Saline Intrusion Practical Modelling of Saline Water Intrusion

Welcome to lecture number 34 of this groundwater hydrology course.

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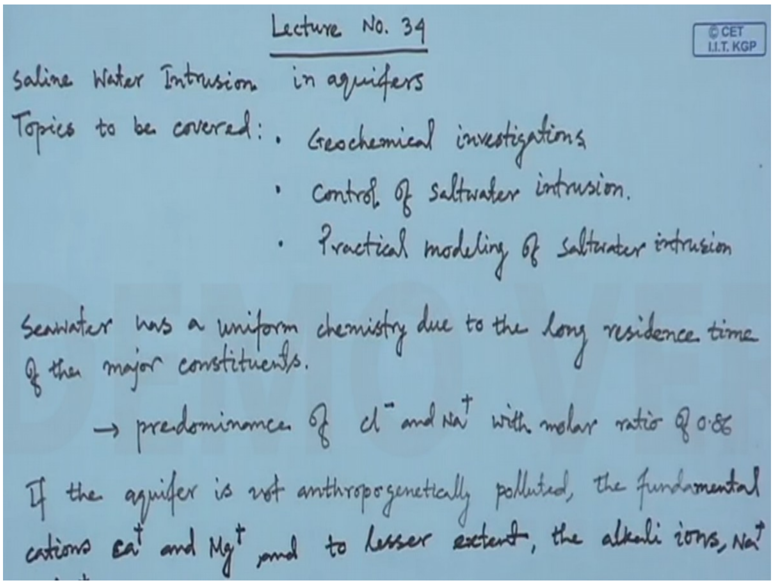

In this lecture number 34 will cover saline water intrusion in aquifers topics to be covered are geochemical investigations control of saltwater intrusion and practical modelling of saltwater intrusion in geochemical investigations we can use some parameters to identify whether saltwater intrusion as happened in the particular aquifer or not.

So sea water has got sea water has a uniform chemistry due to the long residence time of the major constituents so main point is that predominance of chloride and sodium predominance of chloride and sodium with molar ratio of .86 if the aquifer is not anthropogenically polluted the fundamental if the aquifer is not anthrogenetically polluted the fundamental cations.

Calcium and magnesium and to lesser extent the alkali ions sodium and potassium the fundamental cations are mostly this calcium magnesium and to lesser extent they are alkali ions sodium and potassium so to identify the saltwater intrusion different indices or parameters can be defined the first one is salinity salinity so time series of steadily increasing

increasing chloride concentration can indicate the early evaluation the early evolution of salinity breakthrough from sea water.

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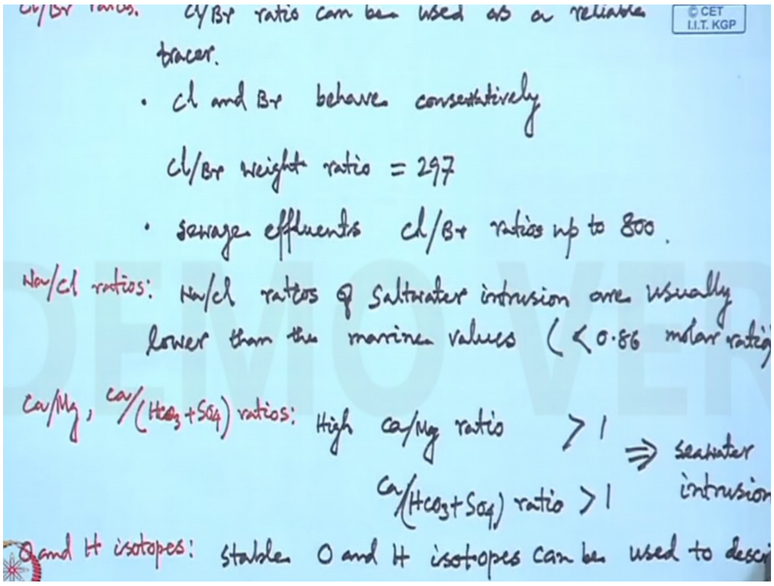

Next parameter is chloride to be our ratio CL or chloride BR or ratio can be used as a reliable tracer because both CL and BR are usually behave conservatively so CL and BR will behave conservatively and in case of sea water this CL to BR ratio this weight ratio is approximately two ninety seven for anthropogenic sources like waste water effluent or sewage effluence.

This CL by BR ratio is up to 800 and the third parameter is sodium by chloride ratios sodium chloride ratios of saltwater intrusion are usually lower than the marine valves which is less than .86 molar ratio the fourth parameter is calcium magnesium or we can have calcium with bicarbonate and saltwater so these two ratios in sea water indicates with pie saltwater intrusion it has got values greater than one.

So high calcium magnesium ratio or calcium bicarbonate plus sulphate ratio both are greater than one indicates seawater intrusion other than this have oxygen and hydrogen isotopes stable oxygen and H isotope can be used to describe the mixing process between seawater and fresh water.

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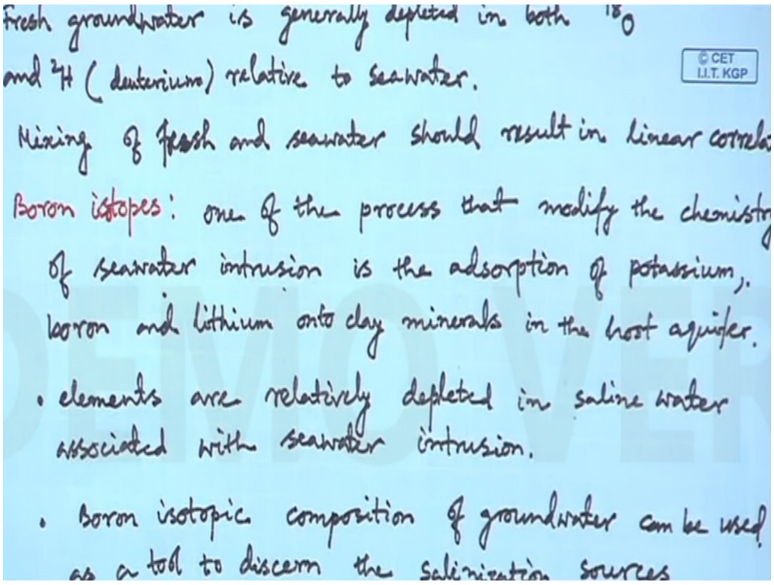

Fresh groundwater aquifer is generally depleted in both and delta M relative to seawater mixing of freshwater fresh and seawater should result in linear correlation the last one is boron isotopes one of the process that modify the chemistry of seawater intrusion is the adsorption of potassium adsorption of potassium boron and lithium on to clay minerals in the host aquifer.

These elements are relatively depleted in saline water associated with seas water pollution so elements are relatively depleted in saline water associated with seawater intrusion thus this boron isotropic composition can be used for identification of Stalinization sources in particular to distinguish from anthropometric contamination such as waste water so boron isotopic composition of groundwater can be used as a tool to discern the Stalinization source.

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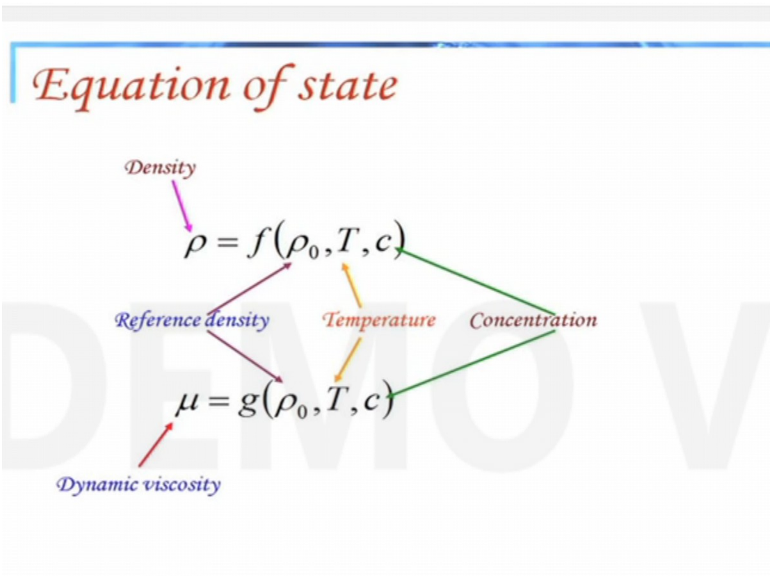

So these are the parameters with which saltwater intrusion can be identified next thing is that in density dependent flow the density depends on the reference density temperature and concentration similarly dynamic viscosity is also the function of density or a dynamic reference dynamic viscosity temperature and concentration. So these two can be treated as equation of state for solving the both flow and transporting the equations.

So for the governing to solve this saltwater intrusion or saline water intrusion process we need to use density dependent flow equations and flow equation is density dependent that means there is relationship between this hydraulic head with density and these equations can be solved in a coupled sets so the first equation is the flow equation. So this is a normal density Rho 0 is the reference density if is the storage coefficient H is the hydraulic head the total head T is time.

So this is time dependent term then we have this is permeability tense or hydraulic conductivity tensor this is this defines the axis direction because the Z direction we need to consider one extra component in case of Darcy's law this Q star this row star is the density of injected or extracted source or sink and Q is the discharge rate of source or sink and this is the transport equation.

So this density is related to this concentration with the relationship that defines that this density is Rho knot + 1 + epsilon or alpha divided by CS where this alpha basically on Rho S - Rho knot divided by Rho knot and this is the density of water groundwater this is reference density this is density ratio or relative density difference so if we take on usual values then this row knot is 1000 kg per meter cube 1000 kg per meter cube.

Then row S is 1025 kg per meter cube then this alpha or then relative density difference ratio that becomes 025 and the CS which is usually concentration of seawater that determines the whole thing.

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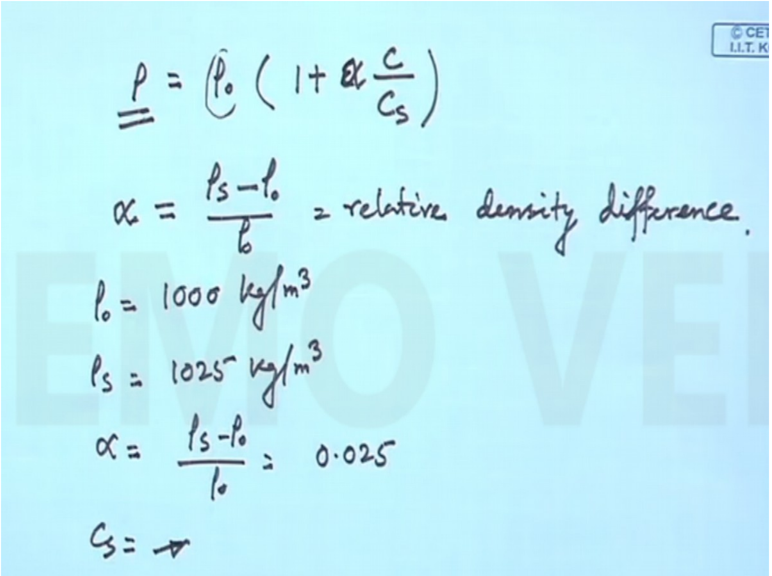

Now in this transport equation this there is moisture content this C is the concentration this is again the temporal or time dependent term this is adjective term and this is diffusive term this is also alpha prime is the modified compressibility term theta is again moisture content concentration this is total head Q is a discharge rate for source and sink and see in is the concentration of incoming or outgoing.

That means the injection and extraction rate similarly the WQ star this row star is the density of the injecting or extraction related fluid .So these are the terms which are there in the transport equation now as we have seen that the density is related to the reference density density is related to the reference density with the relation row and row knot with 1 + alpha and this is concentration divided by CS.

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So we can easily see this two equations are interrelated and it can be solved only in coupled sets so as because there will be saltwater intrusion in coastal aquifers there we need to take some kind of countermeasures so one thing we can do is that we can manage the demand by managing the demand itself we can we can counter this is one kind of counter measures for the salt water intrusion management.

So then non potable water reuse so non potable water reuse is the second measure third one is the modified pumping rate so we can have modification related to pumping rates and with the modified pumping rates only we can control this seawater intrusion then pumping capes with the pumping capes also we can control the saltwater intrusion well location let us say that we have a well which is near to seashore or near to your shore line.

Then it is obvious that there will be extra pumping from those wells and due to these pumping there will be intrusion of seawater and at faster rate and if we relocate it in the inward direction then at least we can check that seawater intrusion in the coastal aquifers then conjunctive use conjunctive us is that we can use a different combination of surface water groundwater.

So that people can use a percentage of groundwater from a coastal aquifers and a percentage from surface water or nearby rivers so that way people will not be that much dependent on the groundwater aquifers or coastal aquifers and w can check the saltwater intrusion and the first one and the last one is the aquifers storage and recovery so aquifer storage and recovery is the most important one because we can store water in the certain aquifers and we can extract that water in the future that way if that is connected to the seawater phase.

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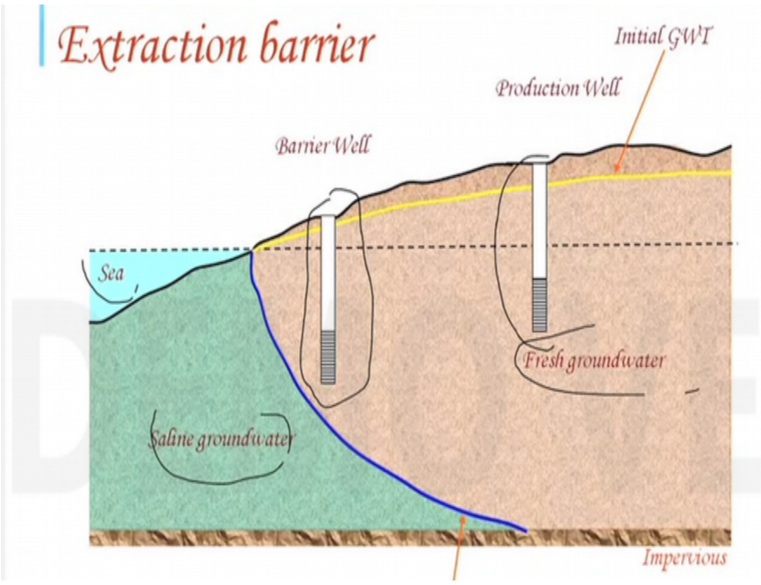

Then it can be it can act as injection barrier also if it is not hydraulically connected with the aquifers so we can store good quality of water in the aquifers and w can use it in future so tapping alternate aquifers let us say that there is saline water intrusion saline water intrusion in this particular aquifer then one can try to tap a lower aquifer which is not hydraulically connected or not that much affected due to saline water intrusion.

So that way we can control the seawater intrusion basically it is by reducing the demand from this particular aquifer and we are transferring that extraction from a different aquifer or we are transferring that extraction thing to a different aquifer next is extraction barrier let us say that we have see here then saline groundwater this is our freshwater and this is our production well.

So and this is another barrier well which is near to our coast and this is our initial groundwater table so if we start pumping there will be movement of this saline groundwater towards the freshwater fresh groundwater or freshwater aquifer and this barrier well will act as some kind of semi barrier thing and it will reduce the sea water intrusion effect by pumping saline water from the pumping wells and we can safely use our production well for some amount of extraction but there should be sufficient limit or there should be caps.

So that we can check the saltwater intrusion so this is the original interface and now the final interface after the seawater intrusion then scavenger wells so these wells are deep wells and these wells are means so that we can arrest the total saline groundwater and it goes up to full depth so this is our final groundwater table this was our initial one.

So we can safely extract water from the production well from our freshwater aquifer injection barrier with the injection barrier in case of barrier well we have already seen that there is extraction barrier now we can use the same barrier well as injection barrier we can inject water into these barrier wells so that water will spread into this aquifer and it will reduce the effect although this movement is shown towards sea.

But this is it is scaled up this is scaled up view there will be a smaller effect or smaller retreat towards the sea now another point is land reclamation with the land reclamation as this is our groundwater table and this is our sea level we can have a different interface position with the land reclamation so that may reduce some kind of seawater intrusion effect and next one the impermeable barrier.

So impermeable barrier is basically made by injecting bentonite slurry or highly some kind of material so that the porosity the pores are filled with that material and the hydraulic conductivity will be reduced or drastically so with this kind of impermeable barrier in position there will be reduced effect and there will be slow movement towards this production well .

So by this method also we can check the saltwater intrusion towards coastal aquifers then another one is the surging pit so surging pit this wall is basically this wall is basically impermeable and these two walls are permeable walls and water is filled in this surging pit and it is just parallel to the coast so with high velocity if we pass some water then the saline water intrusion effect can be reduced this is the production well and there will be reduced effect.

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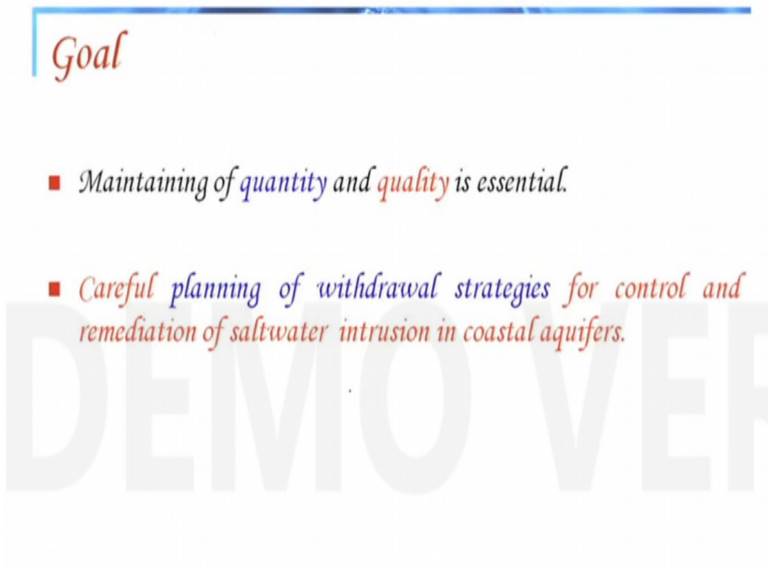

So this is basically one kind of recharge effect and impermeable boundary effect so our goal is to maintain the quality and quantity so we need some kind of careful planning with withdrawal strategies for control and remediation remediation not in true sea.

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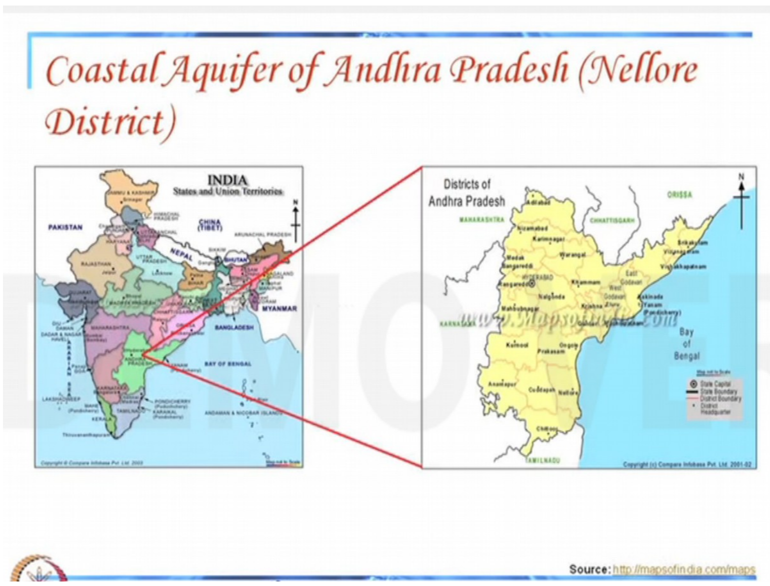

But we can easily control the saltwater intrusion with different type of countermeasures of so now will discuss one case study of Nellore district in coastal Andhra so coastal aquifer in Andhra Pradesh that is in Nellore district so these are two models (()) (41:29) and weather value situated in the Nellore district ands we have taken these two bundles for salt water intrusion modelling and control.

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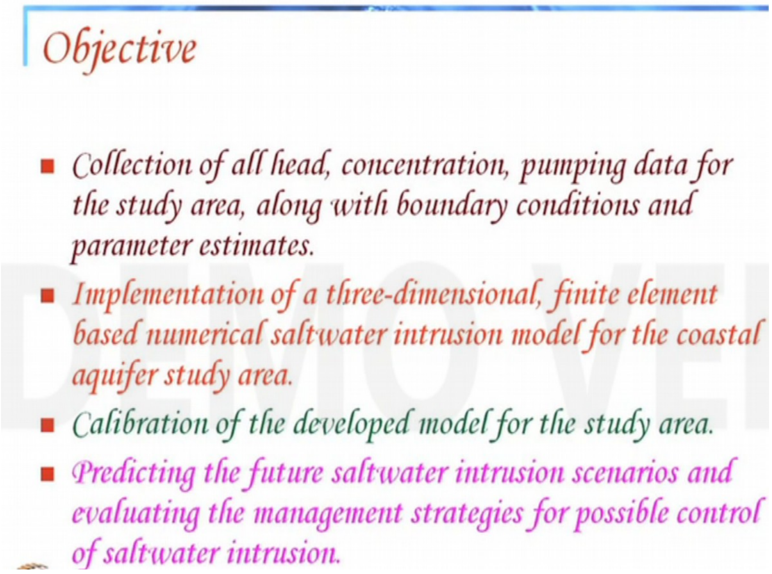

So objective were collection of all head concentration of pumping data for the study area along with boundary condition and parameter estimates next is implementation of a 3 dimensional finite element based numerical saltwater intrusion model for the coastal aquifers study area and calibration of the developed model for the study area and predicting the future saltwater intrusion scenarios and evaluating the management strategies for possible control of saltwater intrusion.

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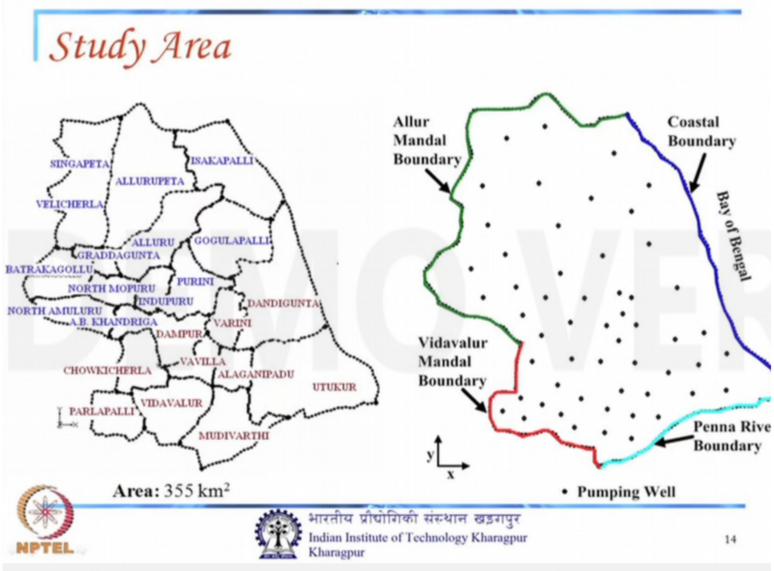

So this is the study area and total area is 355 kilo meters square and this is the boundary between allure and the vidavalur so to model this kind of coastal aquifer regions basically these are having one coastal boundary that is bay of Bengal one is penny river boundary another two boundaries are political boundaries that is allure mandel boundary and by the vidavallur mandel boundary and this black dots these indicates the location of pumping wells.

Generally we have allocated this pumping wells in such a way that it represents the pumping scenario of each of the villages these are the villages which are situated in these two mandels so in a particular village there can be more than one pumping well nut these are basically representative pumping wells for the study area.

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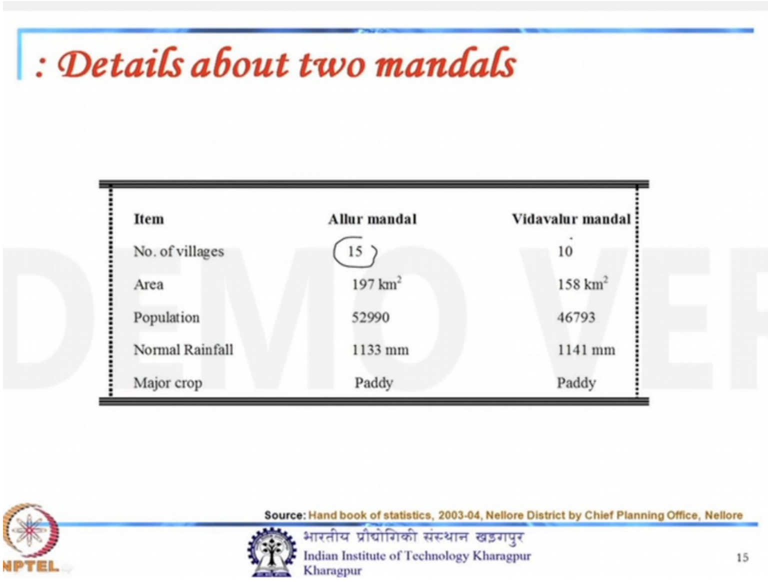

Item	Allur mandal	Vidavalur mandal
No. of villages	15	10
Area	197 km^2	158 km^2
Population	52990	46793
Normal Rainfall	1133 mm	1141 mm
Major crop	Paddy	Paddy

So the number of villages in allure mandel is 15 vidavallur is 10 so area wise is allure is bigger and normal rainfall is almost same and the major crop is paddy but recent few years there has been shipped in the cultivation aspect.

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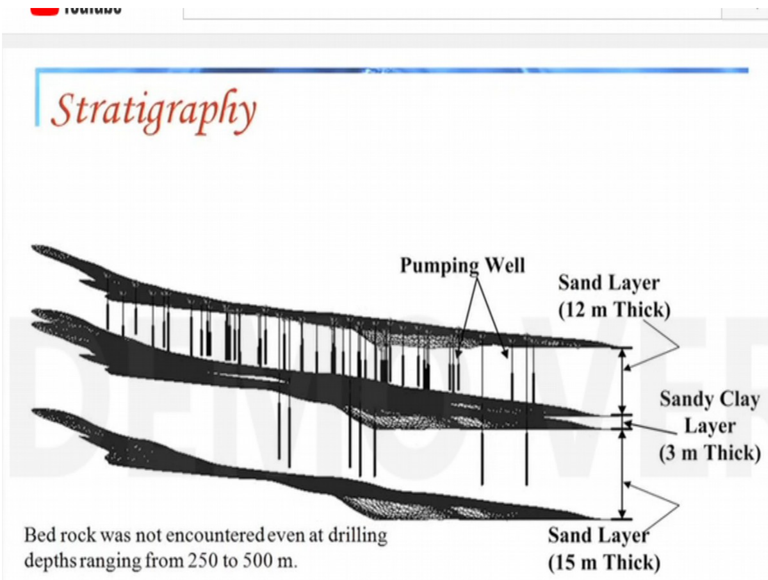

So this is the basic stratigraphy of the study area with the RL values from different sources this model was prepared.

These are the pumping wells these are basically strainers and it has been found that bedrock was not encountered even at drilling depths ranging from 250 to 500 meters. So we have considered the top portion only for modelling so first thing is that we have considered 12 meter thick sand layer then second one is 3 meter thick sand clay and the last one is sand layer with 15 meter thickness.

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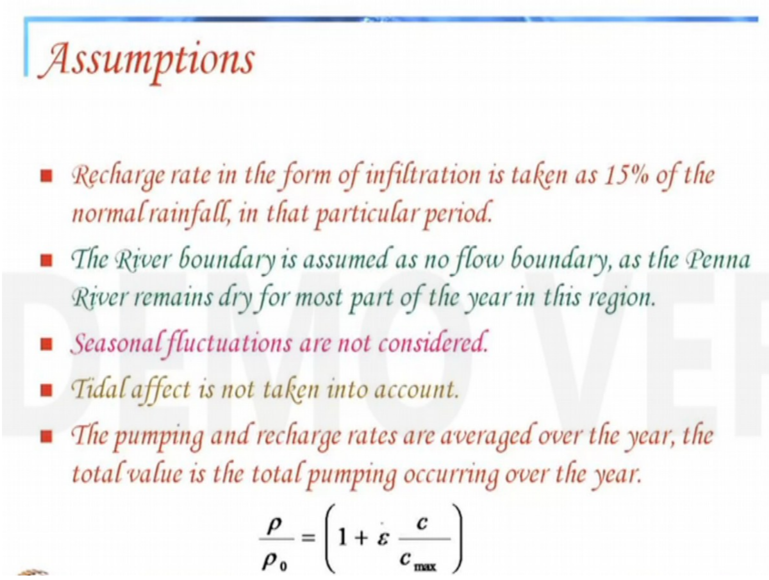

So assumptions that were made because of non availability of some of that set recharge rate in the form of infiltration is taken as 15% of the normal rainfall in that particular period the river boundary is assumed a snow flow as spinner river remains dry most part of the year in this region although there is some amount of discharge but we have assumed.

It is a no flow boundary or not contributing the study area seasonal fluctuatations are not considered a tidal effect is not considered then pumping and recharge rates are average over the year the total value is the total pumping occurring over the year we already know this is the equation in case of epsilon there was alpha.

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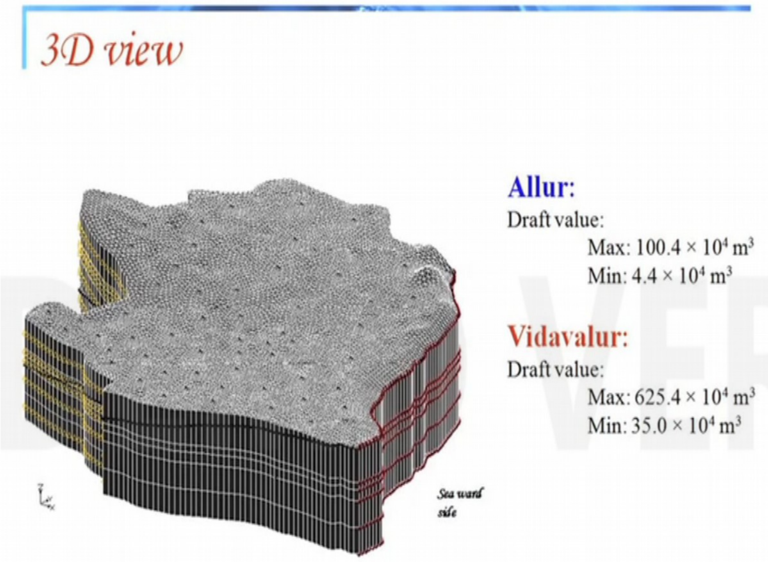

So this is the 3D view of the study area and this is with finite element image and you can see that for dropped values the maximum dropped values assigned for a particular well is this much and minimum is this much and in case of whether volume it has been found that droughts are very high so you have increased the draught based on the population and other data.

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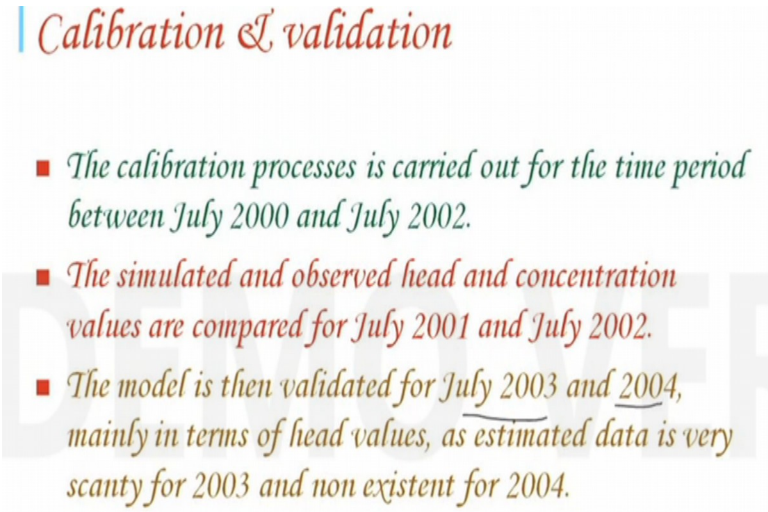

So calibration and the calibration process is carried out for the time period between July 2000 to July 2002 and stimulated and observed it and concentration values are compared with the July 2001 till July 2002 the model is the validated for July 2003 to 2004 mainly in the head terms of head values and as estimated data is very scanty for 2003 and non-existence for 2004 longitudinal dispensability is considered as 50 meters and lateral dispersivity 15 meters.

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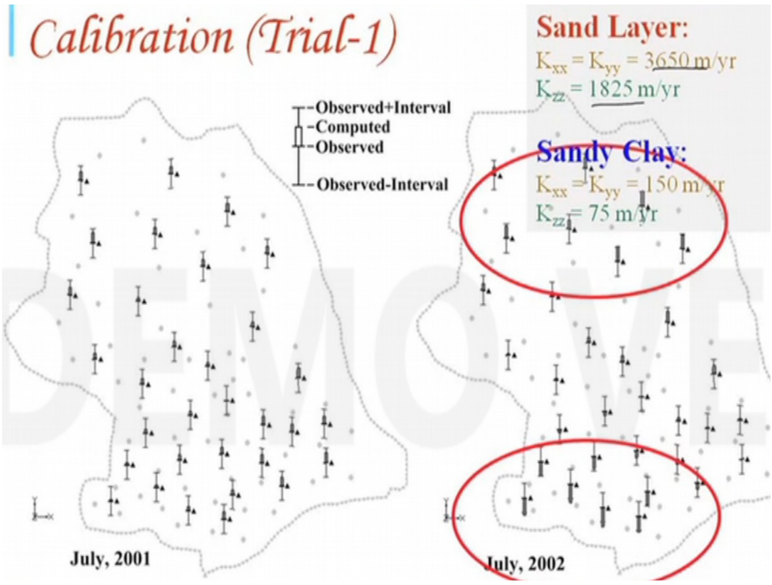

So calibration trials with sand layer with particular hydraulic conductivity values it has been found that the upper region and the lower region that is not matching and also upper region there is some kind of deviation nut not that much but in the lower part it is not completely matching it may be due to the parameter values or due to the boundary conditions.

So groundwater modelling is basically it is either it can adjust the boundary conditions or depending on the actual values or if we do not have that you can try to adjust the parameters to get the actual value so calibration trial two so that one also it has been found that there is deviation in the lower portion or with evaluation and third trial also.

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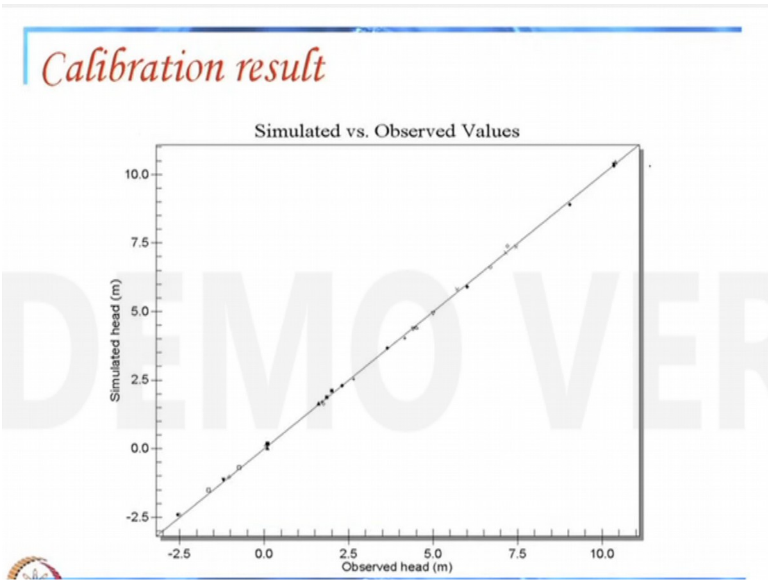

It is not matching so in case of 2001 it is almost ,matching with the actual one so it has been found that stimulated and observed values are well in this 45degree line.

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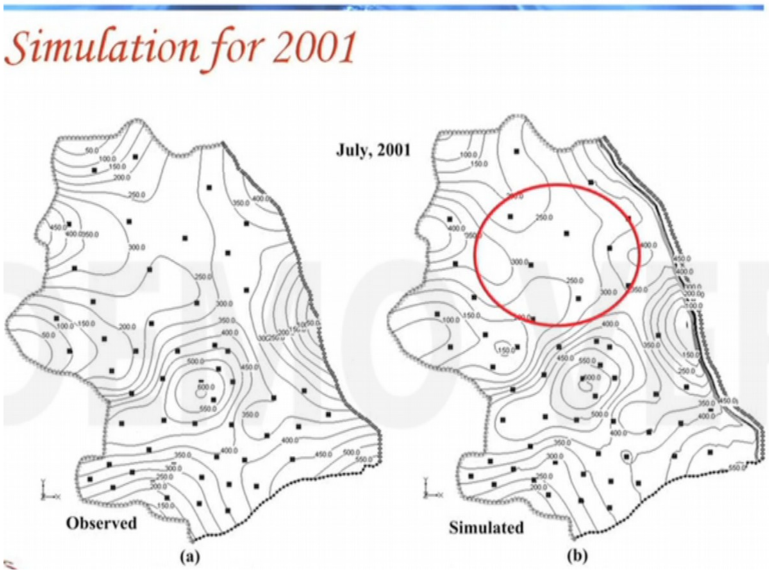

And stimulation for 2001 so stimulation difference so concentration scenario difference here in the internal portion this is observed one this is stimulated.

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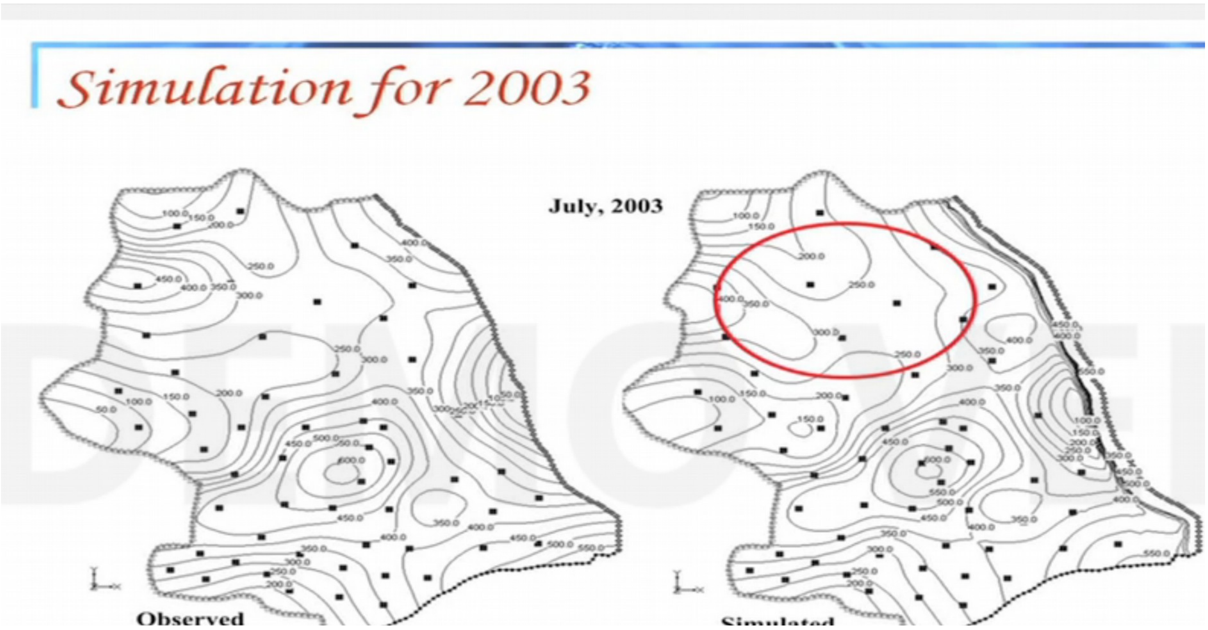

One and stimulation for the 2002 also it has been found that observed and stimulated the middle portion only there is some kind of deviation and this stimulation for 2003 also it is found that there is some kind of deviation for that same region and stimulation for 2009 with the existing pumping pattern this is the scenario but it has been found that internal region we have high concentration values this is due to the fact that there can be some kind of inland salinity for this region.

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So three scenarios are considered for control of salt water intrusion so in the value region the five wells are considered near to well near to seashore.

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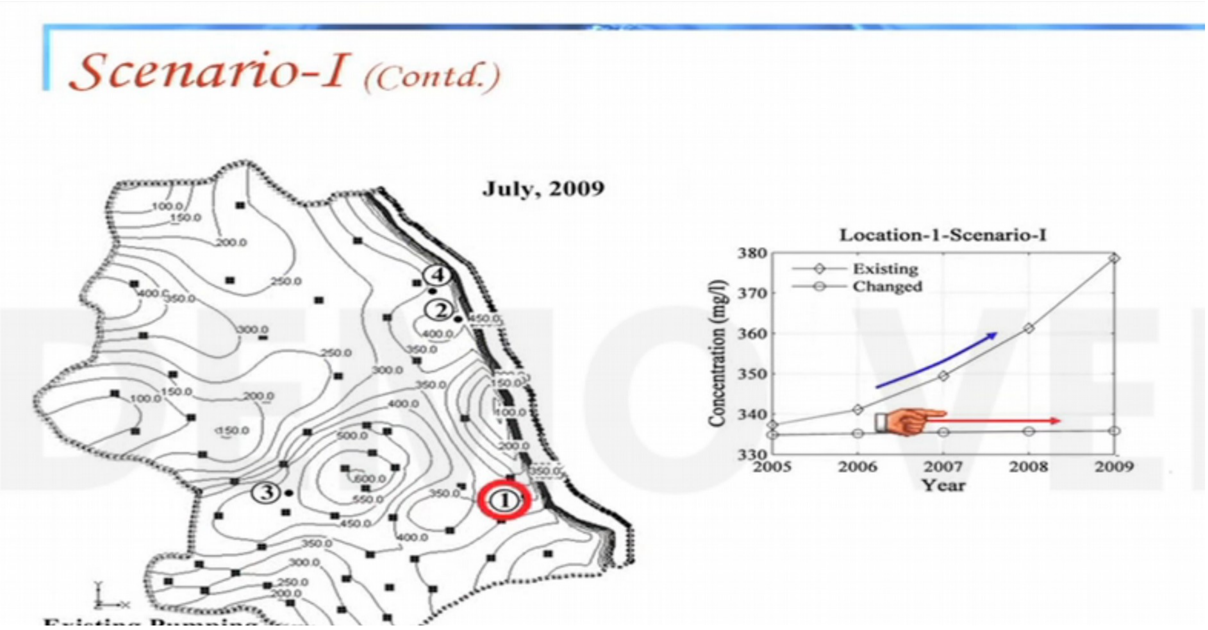

Then it has been shown that there is decrease in concentration for reference point one with the scenario again near the allure mandel if five wells are installed as extraction barrier wells then for dereference point also there is increase in concentration level but the rate is much slower as compared to the existing pattern

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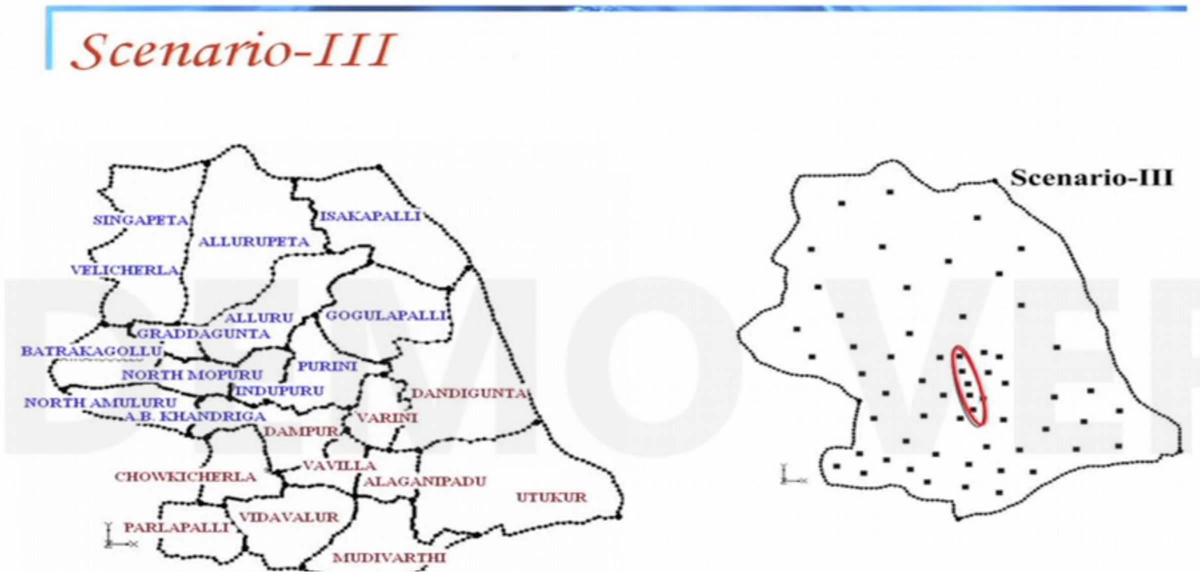

So scenario 3 if 3, 5 wells are installed within that inland salinity portion then also there will be increase there will be decrease in concentration values for that region.

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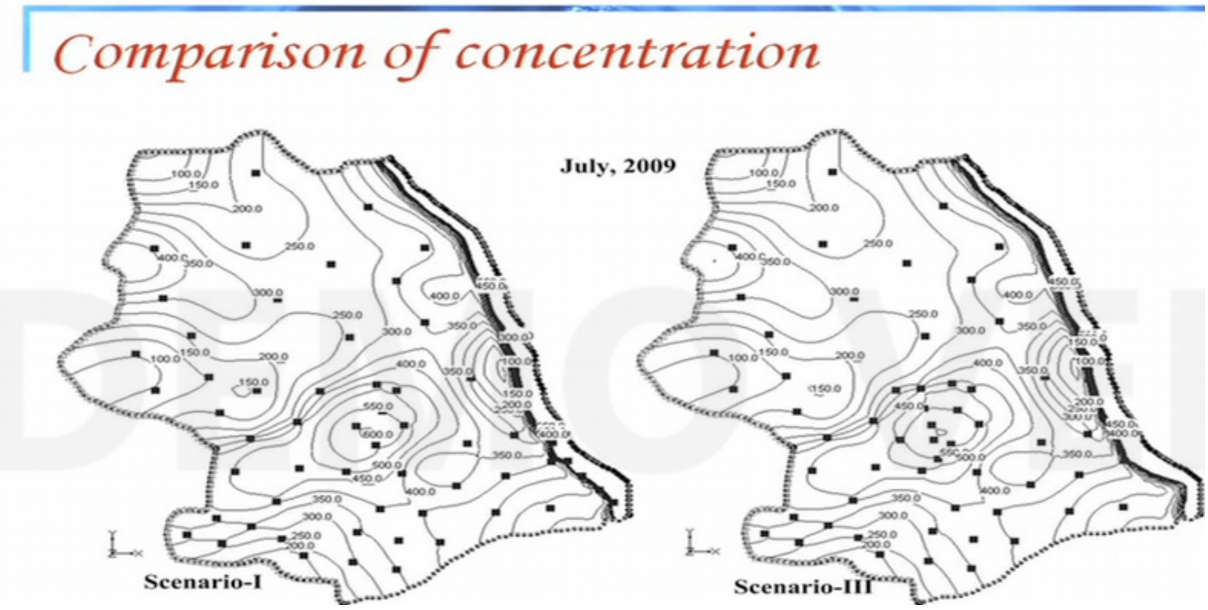

So this is the comparison of concentration for 2009 scenario one and three the scenario 4 also same thing has been experienced.

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Descriptive-Prescriptive formulation

$$\text{Maximize } f_1(Q) = \sum_{i \in \bullet^Q} \sum_{k \in \bullet^T} Q(\mathbf{x}_i, t_k) \qquad \textit{Production well}$$

$$\text{Minimize } f_2(q) = \sum_{j \in \bullet^q} \sum_{k \in \bullet^T} q(\mathbf{x}_j, t_k) \qquad \textit{Extraction barrier well}$$

Subject to the constraints:

$$\mathbf{c}(\mathbf{x}, t) = \mathbf{g}(\mathbf{Q}, \mathbf{q})$$

$$c(\mathbf{x}_l, t_k) \le c_{\max} \quad , \forall k \in \bullet^T, l \in \bullet^O$$

$$Q_L(\mathbf{x}_i, t_k) \le Q(\mathbf{x}_i, t_k) \le Q^U(\mathbf{x}_i, t_k) \quad , \forall k \in \bullet^T, i \in \bullet^Q$$

$$q_L(\mathbf{x}_j, t_k) \le q(\mathbf{x}_j, t_k) \le q^U(\mathbf{x}_j, t_k) \quad , \forall k \in \bullet^T, j \in \bullet^q$$

We can have two objectives for any salt water intrusion management model that is production well extraction barrier well this is the groundwater flow transport equation which relates the concentration with the flow transport relationship there should be some kid of some kind of limit on concentration that means the concentration in the region should not exceed .

Some value and the pumping there should be cap on the pumping values and this is basically maximizing the pumping from production well minimizing the pumping from extraction barrier wells and both pumping from production well and pumping from barrier wells these are bounded values.

So that way one can formulate the management model for saltwater intrusion and it can be solved for any particular aquifer so this is the end of saltwater intrusion con saline water intrusion modelling and basically geochemical investigations control of saltwater intrusion practical modelling of saltwater intrusion and last we have discussed this management aspect of saltwater intrusion thank you.