Water Resources Systems

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Lecture No # 40

Multi-basin and Multi-reservoir Systems

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Good morning and welcome to this the 40eth lecture, of the course, Water Resources Systems, Modeling Techniques and Analysis. Over the last few lectures, we have been now, discussing model formulations for specific problems. For example, we started with the conjunctive views of surface and ground water.

Then, we went on to look at the hydro power optimization and in the previous lecture, I discussed crop yield optimization, which especially is useful in the problems relating to irrigations scheduling. Where, we would likely to allocate a given amount of water in different time periods and specifically to a number of crops, all of which are competing for the same amount of resource.

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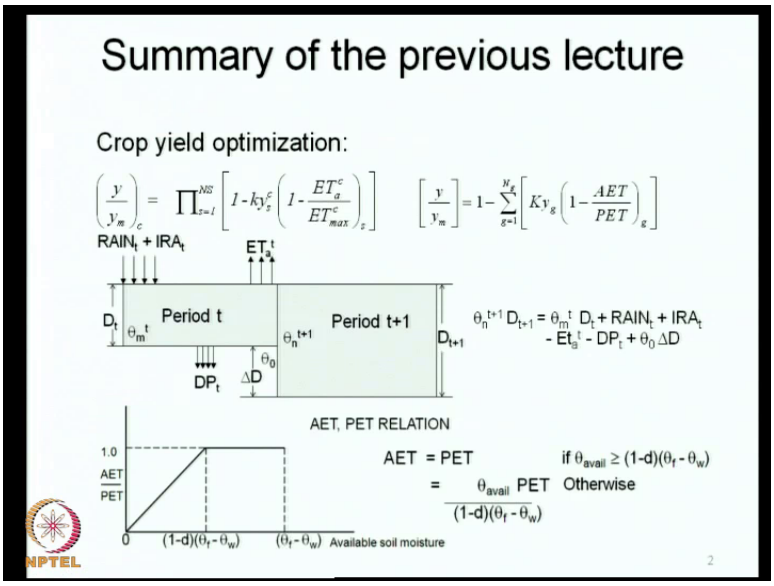

So, in the last lecture what we did was… that we look at the crop production functions. For example, you may have a multiple multiplicative production function; you may have an additive production function. Typically, they relate the actual evapotranspiration to potential evapotranspiration ratio to the actual yield to the maximum yield ratio.

Here also AET is the actual evapotranspiration and PET is the potential evapotranspiration and typically, this production functions are different for the deficit evapotranspirations. For example, 1 minus AET by PET, here also 1 minus AET by PET; ET a and AET are same, actual evapotranspiration for crop c here and potential evapotranspiration for crop c. So, when you write for a single crop, we look at AET by PET for the growth stage g and here also, we are looking at the growth stage s for the crop c. So, this is for crop c.

We specifically, discussed the soil moisture balance from time period t to time period t plus 1 and typically, as I said this periods can be of daily interval, but in many cases we aggregate the soil moisture, lump it over the period of time 10 days. So, this can be 10 day period.

So, starting with the given soil moisture, we know how to obtain the end of the period soil moisture. Starting with the given soil moisture at the beginning of the time period t, we know how to obtain the soil moisture at the end of the time period t, which is also the beginning of the time period t plus 1.

We add the rainfall and the irrigation allocation, we take out the evapotranspiration, we take out the deep percolations, if any and we also account for the soil moisture in this additional soil layer that gets added from period to period. So, we are accounting for the increasing root depth across time here, when we are doing the soil moisture.

In obtaining the actual evapotranspiration, we have used a relationship like this. Which depends on the available soil moisture, that is the actual evapotranspiration to potential evapotranspiration ratio depends on the available soil moisture, by available soil moisture I mean the soil moisture minus the wilting point. So, the maximum available soil moisture will be correspond to the actual soil moisture being at field capacity. And there is a depletion that is allowed by that… I mean the soil moisture can go down up to certain point, without affecting the actual evapotranspiration being equal to potential evapotranspiration.

So, in this range AET is still equal to PET, beyond this range the AET starts decreasing and then at available soil moisture equal to 0 which happens, when the actual soil moisture is at wilting point the AET becomes 0 and that is the condition that will put in optimizations.

So, looking at all of this together, we formulated in the previous class. A linear programming problem through, which we obtain optimal allocations, first we considered a problem of a single crop and where are looking at optimal allocations of a given amount of water for the entire season, the allocations in intra season time periods. These are the first optimizations problem that we looked out.

Then subsequently, we extended this to multiple crops and then for every time period the water available is known. You are distributing the amount of water known to be available at the beginning of a every time period, intra seasonal time period across the crops. Then I towards the end of the last lecture, I also mention that you can link this problem with there are the operation itself. So, that every time period what should be the water available can be decided in that desired integrated optimizations problem?

Now, in today's lecture, what we will do is? We will look at large systems essentially, large water resources systems. For example, several basins several river basins, and then you are looking lining from one basin to another basin your transferring water. Such huge systems how do we analyzed? And then subsequently, we will also look at one river basin, but with the large number of reservoirs. How do we operate? Or how do we analyze such large water resource systems? is the focus of today's lecture.

The systems techniques in fact, are useful for what are called as screening of alternatives… what is called as screening of alternatives? When you have huge systems let us say, that you have a large river basins such as Narmada, such as Krishna, Mahanadhi etcetera, where are even the damodar valley corporation, where you have from 5 to 14, 15 reservoirs, some of them are medium, some of them are large reservoirs. We need to look at these systems as one integrated system and then analyze these systems. When we are doing that we run several simulation models that is we run a simulation model several times and generate large number of alternatives. Which will provide questions to what if such a situations occurs? How does the system perform? That is, these are the type of questions that will be intera basin answering.

So, what will we do now is? We will take an inter basin transfer system. Which is In fact, a proposed transfer system in India and this analysis is meant for academic purpose is to demonstrate. How such large systems can be analyzed? We built the system system simulations model and then we look at optimal availability of water across the different basins. So, let us understand this type of systems now.

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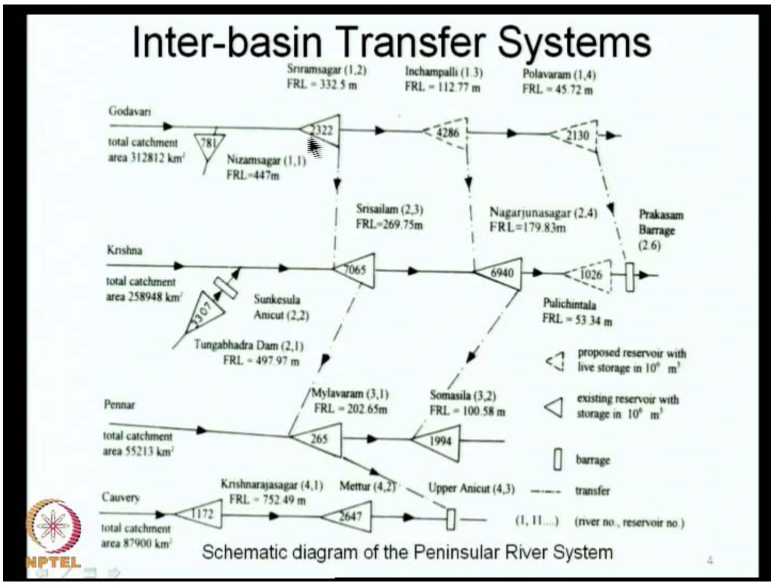

So, as an example, you will take this proposed inter linking scheme, where you have 4 river basins Godavari, Krishna, Pennar and Cauvery. These are the 4 river basins that you have and there are a large number of reservoirs, some of them may be proposed reservoirs, some of them may be existing reservoirs. So, here the continuously triangles here indicate existing reservoirs, the dotted lines triangles indicate proposed reservoirs.

So, you have for the example, you have the Nizamsagar here, Sriramsagar here, on the Godavari, Inchampalli which is proposed, Polavaram which is proposed, then on the Krishna, you have the Tungabhadra coming from a tributary, there you have Srisailam here, Nagarjunasagar, then Prakasam barrage, Pulichintala reservoir which is proposed, then Mylavaram, on Pennar, you have Mylavaram, on Somasila, then on the Cauvery, you have Krishnarajasagar, Mettur and upper Anicut; this is the large system. We are taking about 4 major river basins. The numbers (( )) within the triangles, indicate the storage in 10 to the power 6 meter cube, that is million cube in meters.

So, these are the storage capacities, that are available for each of this basins, the total (( )) is also given here. So, As you can make out from this system along with the numbers that are available, you can see that it is the major system, it is a huge system in fact. Now, when we are considering such systems…

We will also see some other facts here, this links that are shown here, this dotted with arrow links, these are the proposed linking for the basins, that is Godavari is proposed be link to Krishna through this link at 3 points. One is form Sriramsagar to Srisailam, then from Srisailam to Mylavaram, and then here from Inchampalli to Nagarjunasagar, then Nagarjunasagar to Somasilla like this, there are several links that are proposed.

When you are analyzing systems like this, you would like to (( )) place priorities. First of all, we need to build up simulation model, which will reproduce the behavior of such a complex system. As you can see whatever action that you take here, we likely to affect the storage at this point and therefore, that will affect the transfer performance, it will likely to affect the downstream reservoir and so on. Similarly, if you are linking this to the actions that you take at any point upstream of that, is likely to affect all of the downstream points. Suppose, we make a transfer here now, that transfer can be put into use here or that transfer can be put into use here or can be all the way taken back up to this point, upper Anicut. Similarly, transfer that you make here can be taken for use here or for use here etcetera.

So, any action that you take at a point is likely to affect several of the downstream points and we are looking at huge amounts, huge quantities of the water, both at the reservoirs as well as the linking points… as well as the links.

So, how do we simulate this? When you want to simulate at any given reservoir first of all, the reservoir is serving for (( )) purpose is, it may have an hydro power generation, it may have an irrigation demand, it may have drinking in the municipal water demand or it may be protective analyze floods therefore, it has to be protective… it must have flood storage and so on.

SO, at each reservoir now, we will say that first priority is for it to meet it (( )) requirement. So, this reservoir for example, Sriramsagar has been built for a certain purpose. First priorities, meet meet all of these purposes. It has to meet is soon irrigation demands, it has to meet is soon water supply demands, in terms of municipal and industry water supply, it has to meet if at all there is hydro power, it has to meet is soon hydro power demands, it has to account for the plug control, if it is meant for plug control and so on. So, first it will meet all of it is own requirement. Then it will look at this particular reservoir, we will see what is happening to the downstream reservoir of the same basin.

So, if a downstream reservoir of the same basin is in deficit, then if this reservoir is in excess, we will meet the demands of that particular basin through this. Remember here, when I am saying, you meet this demands from this reservoir, it is not for an individual time periods, not every time period, every tentative time period is apply form here and so on.

You have to simulate this system and run the simulation model over a large number of times and then arrive at certain policies. Now, in arriving arriving at search policies, you need to define the priority. So, the first priority as I said is to meet it is own requirements, then you look at the downstream reservoirs for that particular reservoir and see whether you can meet the demands of the downstream reservoir, if it is in deficit.

The third priority will be look at other basins. So, from the Godavari basin, if we are looking at Sriramsagar, first we meet all it is own demands. Then if we are still in access, we meet the demands for the downstream reservoir for the same basins Godavari. If after meeting the downstream demand, if we are still left with water, then we meet with start looking at other basins, whether we can transfer the water to other basins.

I repeat these need not be…This should not be done from period to period that is for every time period, we should not apply this policy. But overall, when we operate this system for long period of time, the simulation model should simulate on an annual scale for example, annually what is the kind of transfer that is possible? Annually what kind of deficit that is possible? In large systems, the time frame of analysis also should be large.

You may typically look at 50 years sequence, 100 years sequence etcetera. So, you simulate this kind of systems (( )) very long period of time and then look at whether such transfers are feasible, whether such transfers are reliable, whether such transfer can be used to increase the irrigation potential, can be used to increase the water supply potential and so on.

So, these systems, because they are especially large you must analyze over a very long time arisen also. So, typically we take 50 years, 60 years, 70 years sequences and not 1 sequence, we analyze this for several such sequences. So, we will see now, how we formulate such a problem?

The fist level exercise is to build a good simulation model, which means what we will have the info sequences that all of this, that is the natural info sequences. We will have at all of these reservoirs, then we may start looking from the downstream most reservoir or from the upstream most reservoir. For example, we may start looking at the downstream most reservoir of a particular river basin. You know the flows that are coming there, then you start meeting the demands, if there is the deficit you go upstream and then whether check whether you can meet the demands from the upstream reservoir, and then 1 by 1 you keep moving in a certain direction either you go for downstream to upstream or upstream to downstream.

Why I say, either direction is, because your running the simulation models several times, it does not matter whether you start from the downstream most and go upstream or upstream most and go downstream, as long as your algorithm is correctly written for that particular direction and then we exhaust all of this transfers and religious, meeting the demands and all of this for a given sequence of inflows, that is how you build the simulation model?

Knowing the demands at each of this reservoirs, knowing the capacity is of the transfer links, knowing the inflows and knowing all the salient features at all of this reservoirs. So, what do I mean by salient features? We have dealt with uglier the features such as the area capacity relationship, storage elevation relationship and hydro power the constraints or hydro power features, that you have at each of this reservoirs, the type of canal system that that I exists, the type of irrigation demands from one time period to another time period, the type of cropping pattern and so on. So, all of this are known at each of this locations.

Then we are trying to see how we simulate this system by simulation? I mean how do we reproduce the behavior of the system for a given set of inputs and for a given set of demands.

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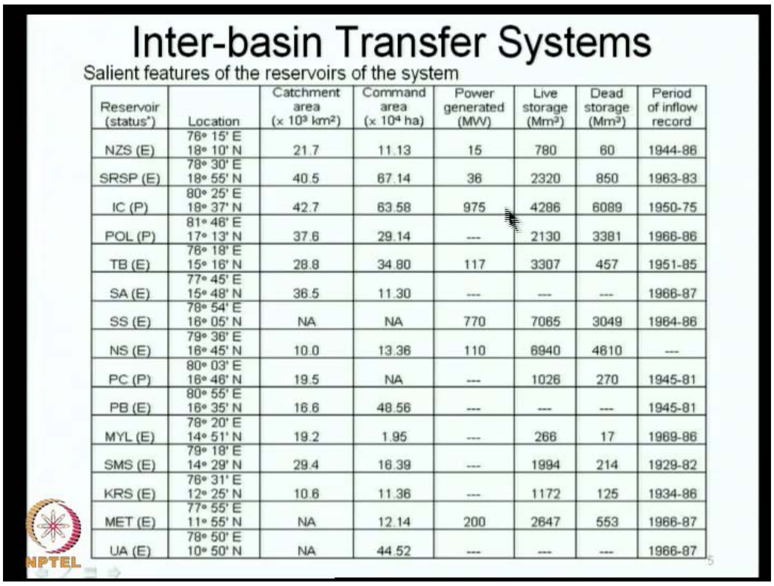

Inter-basin Transfer Systems

Salient features of the reservoirs of the system

Reservoir (status*)	Location	Catchment area (× 10^3 km²)	Command area (× 10^4 ha)	Power generated (MW)	Live storage (Mm³)	Dead storage (Mm³)	Period of inflow record
NZS (E)	76° 15' E 18° 10' N	21.7	11.13	15	780	60	1944-86
SRSP (E)	78° 30' E 18° 55' N	40.5	67.14	36	2320	850	1963-83
IC (P)	80° 25' E 18° 37' N	42.7	63.58	975	4286	6089	1950-75
POL (P)	81° 46' E 17° 13' N	37.6	29.14	---	2130	3381	1966-86
TB (E)	76° 18' E 15° 16' N	28.8	34.80	117	3307	457	1951-85
SA (E)	77° 45' E 15° 48' N	36.5	11.30	---	---	---	1966-87
SS (E)	78° 54' E 16° 05' N	NA	NA	770	7065	3049	1964-86
NS (E)	79° 36' E 16° 45' N	10.0	13.36	110	6940	4610	---
PC (P)	80° 03' E 16° 46' N	19.5	NA	---	1026	270	1945-81
PB (E)	80° 55' E 16° 35' N	16.6	48.56	---	---	---	1945-81
MYL (E)	78° 20' E 14° 51' N	19.2	1.95	---	266	17	1969-86
SMS (E)	79° 18' E 14° 29' N	29.4	16.39	---	1994	214	1929-82
KRS (E)	76° 31' E 12° 25' N	10.6	11.36	---	1172	125	1934-86
MET (E)	77° 55' E 11° 55' N	NA	12.14	200	2647	553	1966-87
UA (E)	78° 50' E 10° 50' N	NA	44.52	---	---	---	1966-87

So, that is what we will look at now, and these are the features for example, this is the Nizamsagar, this is the sardar … this is the SRSP is Sriramsagar, then Inchampalli, Pollvaram, Tungabhadra etcetera. All of these features are known, there is the power generated at certain places for example, Inchampalli you have a 975 mega watts and 770 at Srisilam and so on. So, all of these are the features dead storage, live storage and command area is known, catchment area is known, then the period of inflow record is given here. So, there is a very large period of record.

I would like to emphasize here, that this studies the very old study and therefore, we are stopped around 1987. But the same thing can be taken for word, if more reason data is available. The idea here is not to consider the case study, but to but to indicate how such large systems are analyzed?

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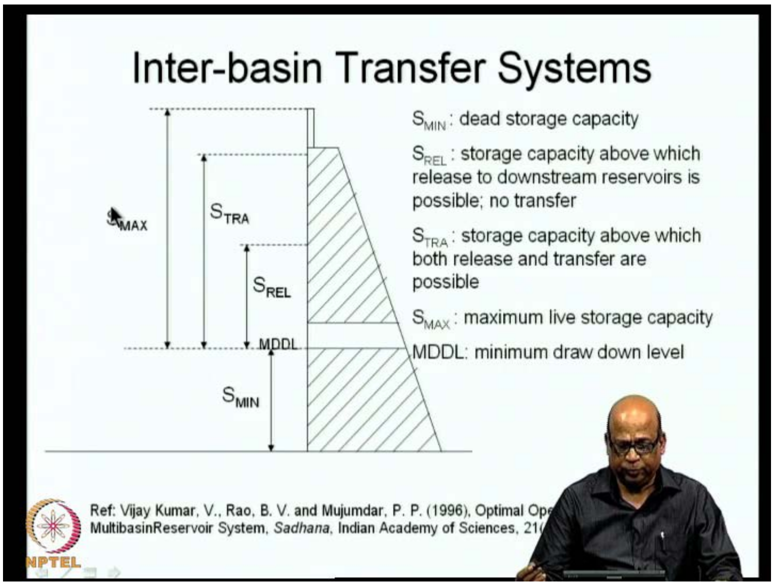

Now, as I said, we will have priorities at individual reservoirs. So, individual reservoirs have to meet their own demands, then after meeting their own demands you look at when you are at particular reservoir, you look at the downstream reservoirs of the same basin. Then if you are if you satisfy the demands from this particular reservoir what I mean is let us say are standing here at this point in the simulation.

In the simulation, we are moving in certain direction and (( )) come to this reservoir. You first satisfy it is own demands, then look at the demands of the downstream reservoirs and satisfy the downstream reservoir demands. If you still have excess water, then you look at the other basin. Other basin to which a link exists, if there is no link, then you do not look at. But if there is the link exists, then we look at other river basin.

This type of analysis, we do by converting the storage or by dividing the storage into various zones. We may say that if the storage is in a particular zone, then you need certain type of religious. For example, you say that after meeting it is own demands. First priority it is to meet it is own demands, until you meet the demands of the particular reservoir, you do not even consider release for the downstream reservoir or transfer to the other basins.

First meet it is own demands, after meeting the demands if the storage is above a certain minimum level, I call it as S REL. So, after meeting it is own demands if the storage is above this particular level, then you make a release to the downstream reservoir. So, S

REL is the storage capacity above which release to downstream reservoir is possible, but no transfer rate so, (( )) this zone, you only make release to downstream reservoir, do not make any transfer, then you have met the demands of it is own of the particular reservoir, then you have also meet the release for the downstream reservoirs and you are you are crossing certain other zone, this is S TRA.

S TRA is the storage capacity above which both release and transfer are possible. So, which means you make the release, you make it is own diversion for the demand and still you are above this, then transfer to other reservoir is possible. Now, the question is what should be this is levels now? S TRA, S REL what should be this levels? Is the question.

The MDDL which is the minimum draw down level is known. The S MAX which is the maximum capacity - maximum live storage capacity from MDDL that is known. So, this two are fix, we need to look at what should be the optimal S REL? And what should be the optimal S TRA?

Such that this large system becomes reliable in terms of it is ability to meet the demands at all the locations and subsequently, if we are able to meet the demands, we will start looking at can we increase the irrigation potential and therefore, can be increase the utilization value of the water itself. There is from one basin to another basin to another basin, you are looking at increasing the value of the water. For example, if we are looking at the downstream most point in the Cauvery basin.

If you have deficit at the locations and if through such transfer links, you are able to meet their demands first and then can we increase the irrigation potential at these points, because you can have excess water from these points. So, these are the two questions that will answer. In answering those as I said you need to look at the zones the storage zones and then ask the question what should be optimal ?

S REL which is the storage zone, above which the release to downstream reservoir is made and S TRA storage zone above, which you make the release for the transfers to other basins, that is the idea now and this we need to do for each of the reservoirs. So, these values should be different for each of the reservoirs obviously.

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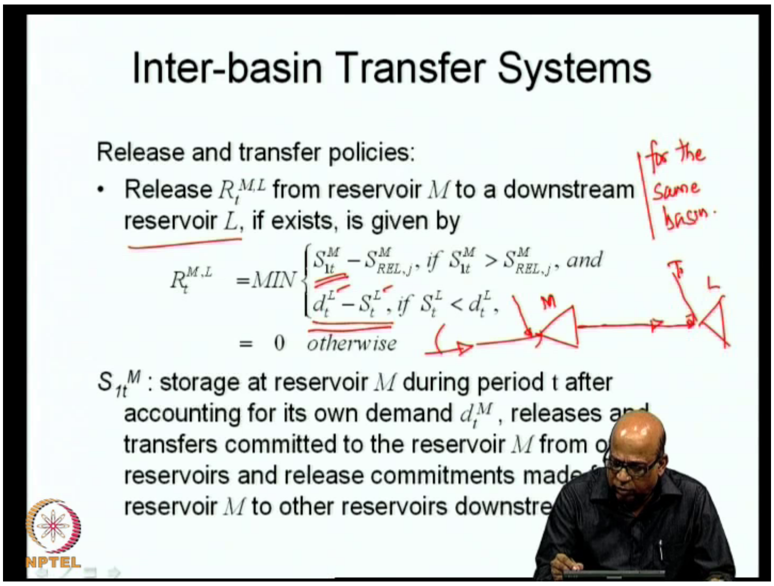

We will now, define the release and the transfer policies. First meeting it is own demand, there is no policy. If water is available simply meet the demand, there is no policy that is the standard operating policy. You look at any particular time period, if there is the certain demand and you have water to meet the demand at that particular reservoirs simply meet it do not look at other reservoirs, do not look at other time periods, do not look at other basins, there is the diversion policy.

Then we look at the release policy that means you have meet the demand at the particular reservoir, but still you have water in excess of S REL. S REL is the storage zone for release to be made to the downstream reservoirs of the same basin. So, that is the release policy. Look at this now, what we are saying there is it? From a particular reservoir M to a downstream reservoir L of the same basin, here when I say this is releases for the same basin.

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So, what we are looking at is? Were standing at a particular reservoir m and were saying a release to be met to reservoir L. First of all this is storage that is the available here in reservoir M, must be greater than that particular zone here. So, we should be this zone.

So, storage must be greater than S REL after meeting it is own demands. So, I will define S1 t here for the reservoir M, that is in the time period t as a storage at reservoir M during period t after accounting for it is own demand d t M, that is in time period t at reservoir M. So, meet all of it is own demands, then releases and transfers committed to the reservoir M from other reservoirs. So, you may have transfers coming from other reservoir of other basin, you may have release coming from it is own other upstream reservoirs from the same basin. You account for all of this input that us come here and then call it us S1 t. So, S1 t is the amount of water that is available.

After you meet the demand and after you account for all of this and if this S1 t is greater than S REL that means, you are here now, after accounting for all the various variables you are have here now storage. Then you make the release, release to downstream reservoirs L. How much do you make? You make a release of whatever is it in excess here or whatever is demands it at this point.

So, you take the minimum of what is available here? Or what is deficit at this point? And the storage L now, what is the deficit d t L is it is demand and S t L is it is storage, after accounting for whatever you have got from that. So, this is the deficit there and this deficit you have to make from this particular reservoir.

So, you make a minimum release from reservoir M to reservoir L. To meet it is own demands or whatever excess water that is available out of that which are is the minimum and this 0 otherwise needs that if neither you are in that zone or that is known deficit here, then you do not make (( ))… you do not make any (( )) in fact so, that is the idea. No when we recommend the deficit at the reservoir L, downstream reservoir L you (( )) accounted for whatever transfers and whatever releases that it would have got. It may have also got some transfers here and it may have got some release form other reservoirs upstream of that, but downstream of M. So, you may have several other reservoirs here. So, all of this you account for and then make the release.

I will repeat that that is the were taking about the release policy, were asking for how much to be release from M to the reservoir L. To meet the demand deficit which is d t minus S t at reservoir L and this is S t L should account for whatever transfers that the reservoir L has got and whatever releases from other reservoirs, that it is at got by release I mean the amount of water release to meet the requirement of the downstream reservoir. So, that is what we look at? So, that is what this is phase and if there is no deficit here, you do not make any release from reservoir M to reservoir L. Much the same way we talk about…

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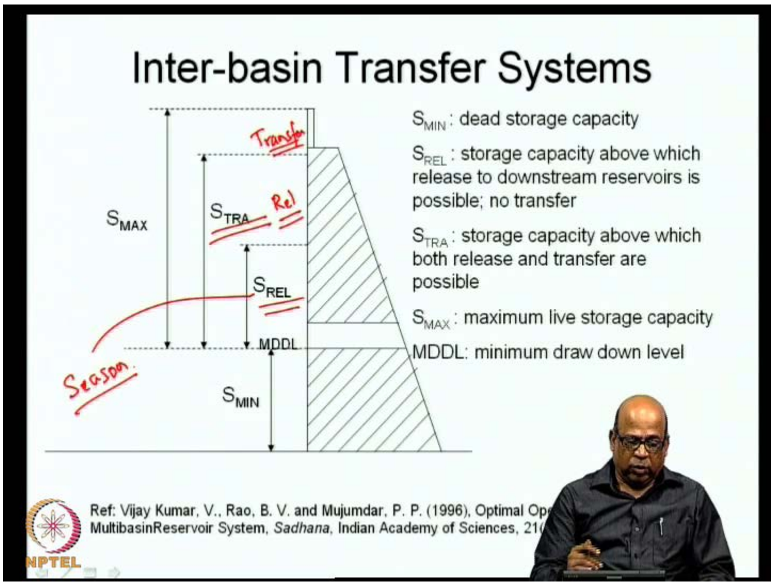

All right there is one more small issue here. We said this S REL and S TRA are the storage zones, that determined the storage zones within which release and transfer is possible. So, in this zone release is possible by release the (( )) amount of water release for downstream requirement, that is the requirement of the downstream reservoir and this is the transfer zone.

If we are above S TRA you make the transfer. Now, these zones are typically defined for season that is you do not change these zones every time period. If we are talking about time, date time period you do not say that during this 10 day time period by zones are like this, during the next 10 day time period this zones are like this etcetera. Typically, these zones are different for monsoon season and non monsoon season or you may also have it for annual season annual time periods.

Simply, have 1 zonic for the entire year. So, this zones in this particular example that I am showing or defined for the season j. So, whenever I am talking about S REL and S TRA with talk about the season j.

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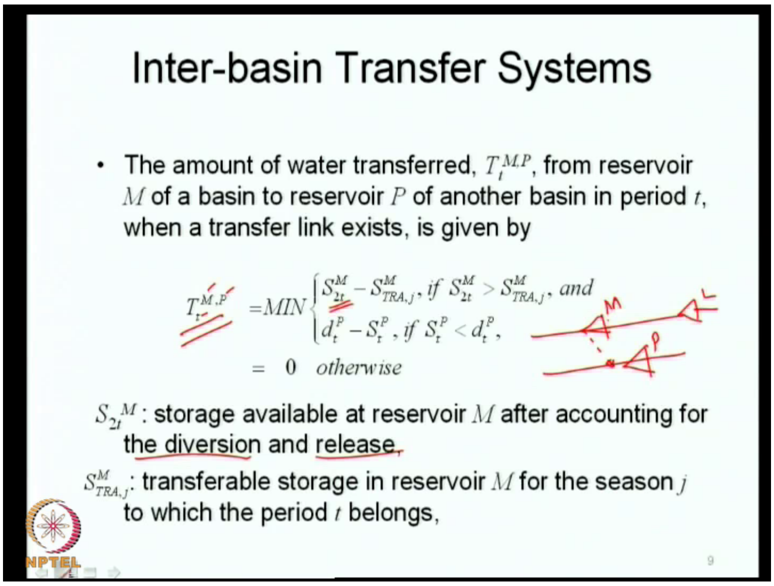

Much the same way, we do that transfer. So, the amount of transfer that we are looking at by release I mean the release for the downstream reservoirs by transfer I mean transfer for the reservoirs in the other basin. So, whenever I used the word transfer it is from one basin to another basin, when I use the word release it is from one reservoir to another reservoir downstream reservoir for the same basin. So, the transfer that is made in time period t from the reservoir M to the reservoir P is whatever looking at. So, this is one basin, this is another basin.

Now, this is one reservoir M and this is the reservoir P here, this two are different basins and there is the link that is exists. So, we are talking about the transfer from reservoir M to reservoir P. Now, this transfer now, we are now introducing S 2 t at M. So, S 2 t M is the storage available at reservoir M, after accounting for the diversion by diversion… I mean meeting it is own demands and release. Release is the release for the downstream reservoirs of the same basin. So, I made met it is own demands, you have met the demands for the downstream reservoirs L and still we are in excess of water, then we look at the transfer. So, that is the amount of transfer.

It is the exactly same as the release policy, except that we are looking at the storage S 2 t now and were looking at 2 reservoirs into different basins. So, this is one basin, this is another basin. So, that is how we decide the amount of transfer from one time 1 reservoir to another reservoir, from reservoir M in one basin to reservoir P in another basin. Then at every reservoir, you will have storage continuity, you will have it is own constraints and so on. So, all of these are typical, multi reservoirs system, simulation which have discussed earlier. So, at every reservoir you meet the storage continuity equations and then we put on top of all of them, the release policy as well as the transfer policy and then you simulate the system.

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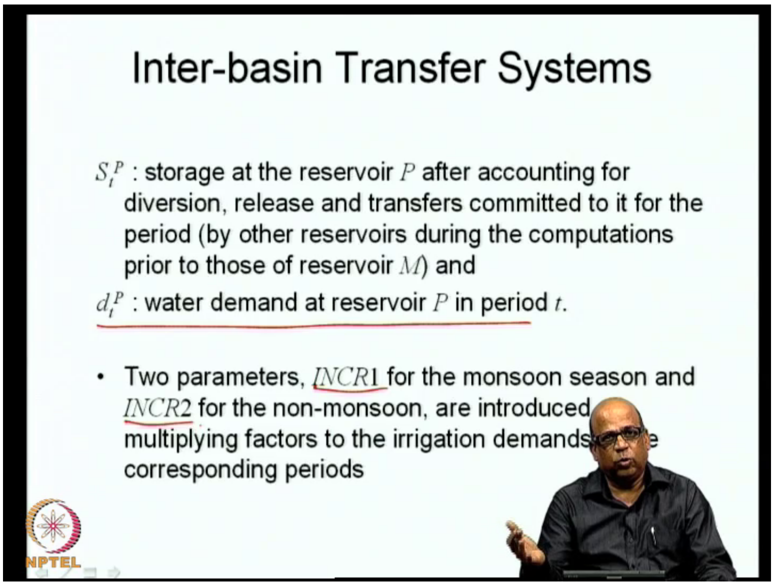

So, this is the transfer policy and then we will do as a said, when we are able to meet the water demand at each of the reservoirs by accounting for releases, by accounting for storages and so on. When you do this, if you see that all the demands are met… all the existing demands are met. Then you start looking at can we increase the demands what I mean by that is can we increase the irrigation potential, can we increase the hydro power potential, can we increase the municipal and supply potential. So, once we are able to meet all the demands, then we start looking at to the to what extends we can increase the irrigation potential, to what extends it can increase the hydro power potential etcetera. So, start multiplying the demands and then start looking at how best water can be utilized. And that is where we put 2 factors INCR1 and INCR2 for the two seasons, monsoon season and non-monsoon seasons. To see in monsoon season whether we can increase and by what extend we can increase and in non-monsoon season to what extend we can increase.

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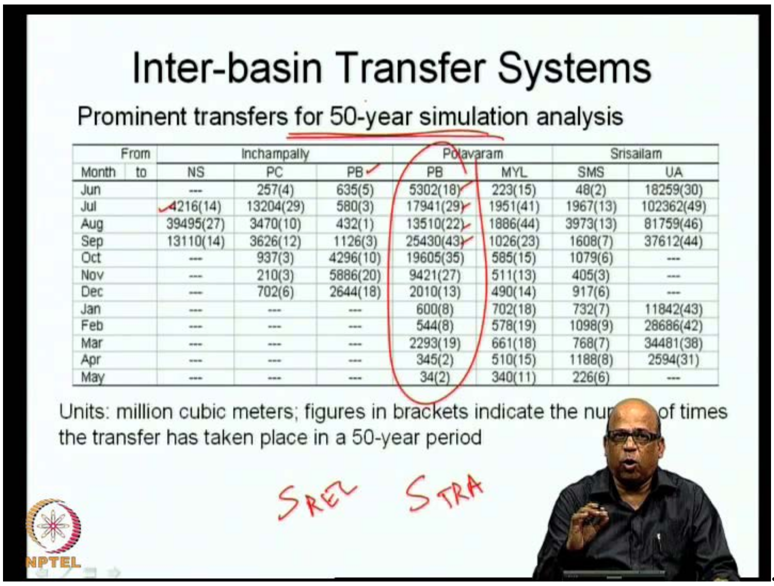

So, like this we do the simulation and the type of analysis that we get. We do 50 years simulation, this is the just a summary. It shows now, here from one point to another point, what is the kind of transfer that has taken place. So, the first figure here shows the transfer from Inchampalli to Nizam that is NS is Nizamsagar. So, that is the transfer that is possible from Inchampalli to Nagarjunsagar… from Inchampalli to Nagarjunsagar. So, this is the type of link that we have here. So, we can make the transfer from Inchampalli to Nagarjunasagar and that is the type of transfer that we get from one point to another point.

Similarly, Inchampalli to Prakasam barrage and Inchampalli to Pulichintala and so on. So, Polavaram to Prakasam barrage, Polavaram to Mylavaram and so on. Now, it may not be direct link, but it can be an indirect link what I meant by that is you may have a link from here Inchampalli to Nagarjunasagar and from Nagarjunasagar you may have a link to the Somasila.

So, you can talk about from here to here or from here to here. Similarly, when you are from Sriramsagar you can come to Srisailam, then to Mylavaram, then to Somasila. So, the transfer if you have excess from water here, you can take it all the way up to upper anicut. So, we can show this as Sriramsagar to Srisailam to Mylavaram to upper anicut.

So, that is the way we analyze the system and these are the number that we have got for 150 year simulation. What do you mean by 150 year simulation? We may have several such sequences I will talk about this in subsequent example. Where we generate not one sequences, but we use several such sequences and do several such analysis to obtain what kind of transfers that are possible and how many times in 50 year sequence, how many years the transfer has been possible. For example, here 43 times it is possible from Polavaram to Prakasam barrage and so on.

So, this is the type of numbers that you get, remember these are planning models, where you look at an overall picture. Both with respect to space as well as with respect to time over a 50 year time periods. How many times we would make the transfer? And what is the total transfer in the 50 year time period from one basin to another basin? And so on.

Then we ask the question now, this we did with a fixed S REL and S TRA, whatever we doing there is that this zones that I zone S REL as well as S TRA. We start with the particular S REL and particular S TRA at each of the reservoirs. We know this level we know this level and then we start with a given or prespecified S REL and prespecified S TRA. Make the simulation look at how how well the demands have been met? Change S REL change S TRA again do the simulation, again look at how well the demands are met and so on.

So, like this you can keep doing, keep running the simulation model several times, but obviously, because the system is large and you will have S REL, S TRA each of this and 2 search because, we are talking about monsoon period and non-monsoon period. So, at each of them you have you have to deal with 4 variables S REL1, S REL 2 for monsoon and non-monsoon, S TRA 1 and S TRA2 for monsoon and non-monsoon at each of this reservoirs and therefore, doing it manually that means, manually every time you change the S REL and then go to the next simulation run at each of this reservoirs. It becomes not only (( )) not only unyieldly, but also extremely subjective. So, finally, you do not have trust on the optimal reserved that you get and therefore, what we do is the simulation model that we have built, thus we put it into a more formal optimization algorithm.

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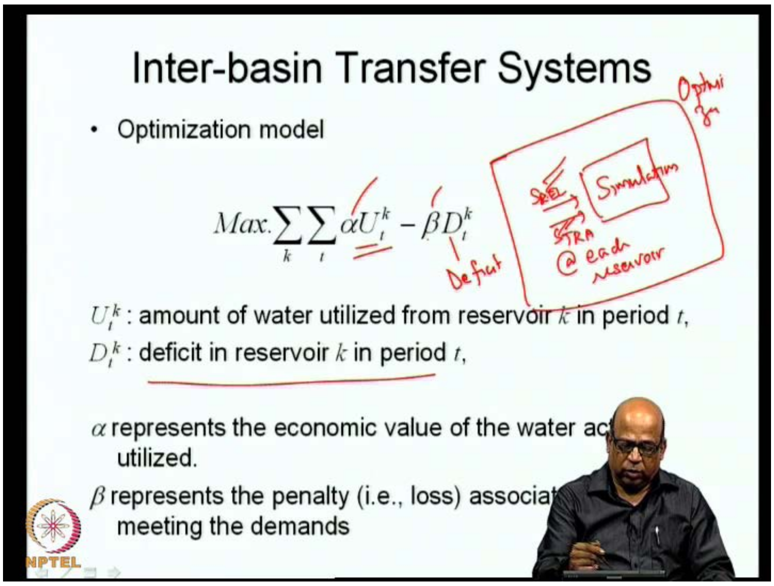

So, there is the simulation that you have to put, this is the simulation model. Now, this simulation model apart from all other inputs, we take inputs as S REL as well as S TRA. At each reservoir and that is the type of results that you get for a prespecified S REL industry array. We know built this whole system into an optimization problem, in which this S REL and S TRA are varied systematically.

So, you may have a non-linear search algorithm, in which depending on the type of system performance major, which will depend as this depending on the system performances measure, it will adjust the values of S REL and S TRA at each of the reservoirs. So, you have a simulation model super impose on it and optimization model. The optimization model will give you the optimal S REL and S TRA, by making search over all possible values of S REL as well as S TRA at each of the reservoirs.

Such that you are able to meet a certain objective and objective function here. We consider for that is now, how we solve is slightly beyond the scope of this course? But you realize that we use a noon-linear search algorithm you can in fact, use algorithm such as genetic algorithm or anticonial optimization and so on. It is such situations where you have to have a large simulation and then on the simulation you need to do on optimization, in such situations the evaluationary algorithms such as the practical (( )) optimization, genetic algorithms, the anionic optimizations etcetera, this can be used here.

Now, in this particular example, that I am showing, we use a simple non-linear search method, which is available in many of the standard scientific programs such as mat lab.

Now, we look at what is the objective function here? We are saying at a given reservoir k for a time period t, where saying the utilization of water in that reservoir for that time period, where calling it as U and the utilization is the amount of water that is used for meeting it is own demand plus the amount of water that the reservoir k has released to meet the demands downstream, that is at the downstream reservoir plus the amount of water that the reservoir k has transferred to other basin. All of these three together will called it as utilizations.

So, the amount of water that is available has been actually utilized and that is the among term U t k that is that is what I am saying here. Then there may be deficit at the reservoir k. So, D t k is the deficit in reservoir. Obviously, this too (( )) cannot occur… I am sorry I will repeat that U t k if it consists of release and transfer terms, then D t k cannot occur because, D t k would be first met a out of the U t k.

So, D t k is the deficit from it is own demand that means, the water was not sufficient to meet it is own demand in reservoir k in time period t that is the deficit and we associate values alpha and beta, these are constants. These can be economical returns or economic value are (( )) to the water that is utilized alpha and the economic loss that is (( )) to deficit. But this can be wilt age factors you can look at it as the multi objective problem and then assigned waits and play around with the waits to get different solutions.

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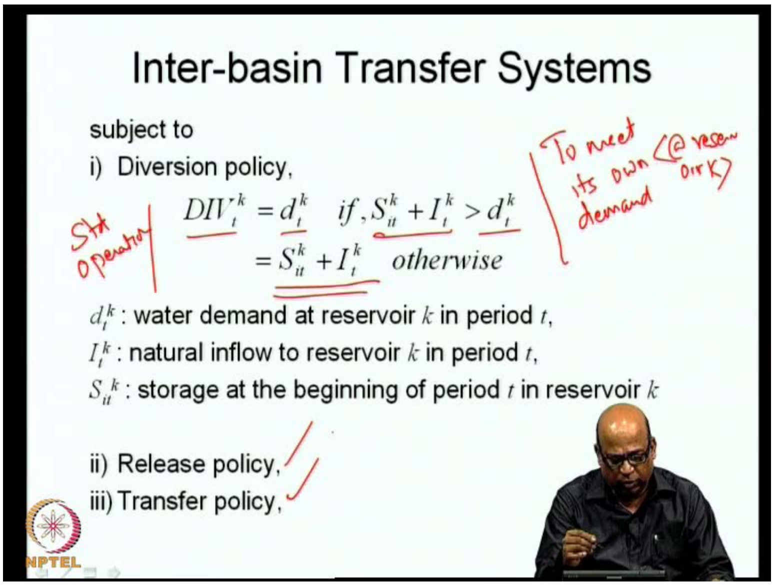

Then we have the diversion policy that is to meet it is own demand.

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Now, it own meets at the reservoir k.

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This is us the standard operating policy that means, you look at the water that is available, if it is greater than the demand you meet all the demand, if it is not greater than demand, then you bring down the reservoir reservoir storage to 0; that means, you release all the all of the amount of water available S i t k plus I t k for to for meeting the complete demand d t k.

Now, in addition you will have the release policy and writing the optimization problem. Now, we are writing the objective function, we are writing the diversion policy similarly, we write the release policy. Release policy is the same as what we put depth. This is the release policy and similarly, the transfer policy. So, these become constraint. So, release policy is set of one constraints, the transfer policy is another set of constraints.

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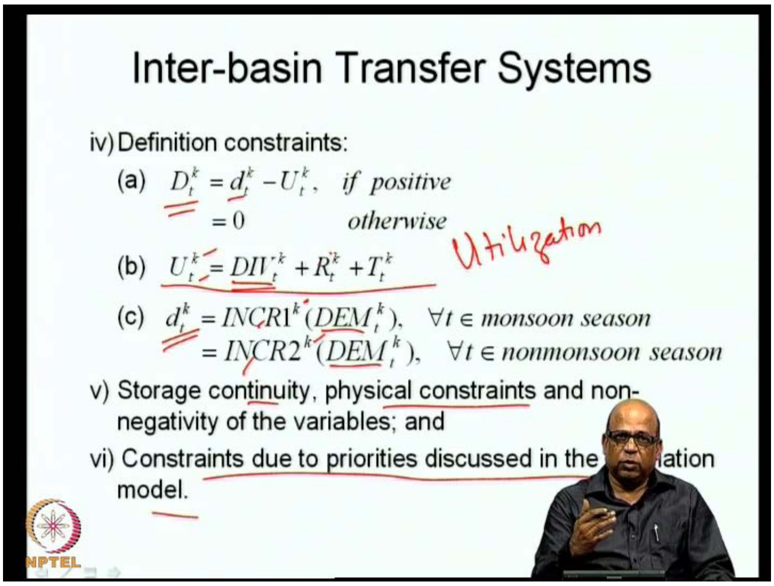

And then you have the storage continuity equation, physical constraints for example, the canal capacities, the hydro power install capacity, the storage being limited to the minimum storage and the maximum storage etcetera. All the physical constraint you will have and then non negativity of variables and also then we may have constraints due to priorities that means we will have to say, that first you meet it is own demand. Only then you consider the release, only then you consider the transfer, which are the potential transfer of the release policy as well as the transfer policy, then we have the definition constraint. For example, you look at U t k, this is the utilization.

The utilization at reservoir k in time period t is first it is own demand, diversions is for it is own demand. Then release for meeting the downstream demand that is demand at the downstream reservoir, then this is the transfer. Similarly, this defines the deficit D t k that is demand minus the utilization. As I said if there is the release and transfer or if there is a release, then U t k will be consisting of that is the demand will be completely met.

Because, diversion k will be equal to the demand k and therefore, it will be 0, otherwise. So, that is the definition for D t k deficit and this small d t k which is the demand we will now, put it as the specified demands DEM t k is the specified demands, we multiply to see whether we can increase the demands at the reservoir k. So, that is the factors. These factors also come out as decision variables, when we solve the problem that is at each reservoir.

Remember they are not changing with respect to time, at each reservoir simply we are saying that how by how much factor what factor we can increase the irrigation demands ? that is the question that we are asking, then all the physical conditions etcetera. So, the simulation model that we have built earlier, we now, formally put it as an optimization problem where there is a search over all this variables decedent variables S TRA 1, S TRA 2, S REL 1, S REL 2 at all of this reservoirs and INCR1,INCR2 at all of this reservoirs. So, the non-linear programming makes a systematic search and then finally, gives you the optimal solution.

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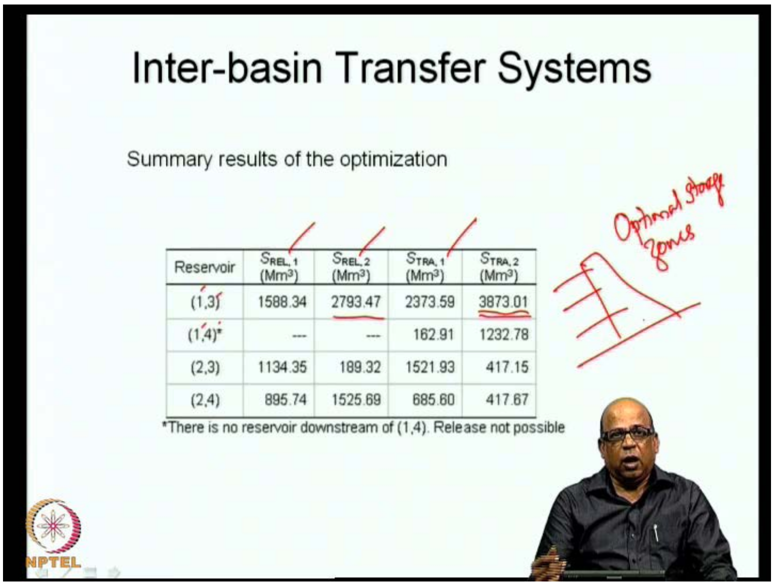

In terms of, what are the S REL 1, S REL 2 at each of these reservoirs? Now, (1, 3) (1, 4) explain at indicate the basin number and the reservoir number. So, the basin number 1 is Godavari and reservoir number 3, 1 and 4, 2 and 3, 2 and 4 like this. So, for all of these you get the storage zones. Now, for example, (1, 4) if we look at (1, 4) this notations are for 1 is the reservoir 1 is the basin, 4 is the reservoirs. So, this is Polavaram is (1, 4).

Now, if we do not have anything downstream, there is there is no downstream demand the obviously, release term will be 0 whereas, transfer term may be possible. So, you may not have a release zone, but you may have a transfer zone. So, that is how you put the optimal results here.

So, finally, what you get out of the optimal solution? is that you are making the transfer zone as well as release zone for both monsoon as well as non-monsoon periods. So, this is where saying at the reservoir (1, 3), the S REL 2 will be 2793 million cubic meters, which means only when you cross this storage you start releasing. Similarly, if you cross this storage 3873 million cubic meters, then you consider the transfer.

So, by doing these optimization what we have achieved is at each of this reservoirs where defining the zones. So, the optimal zones.Optimal storage zones are what we get out of this.

Then we ask the question how good are the solutions, if we meet all of this, it has maximized some objective function and therefore, it has done some non liner search and finally, provided as with the optimal storage zones at each of the reservoirs. But how does the system perform if we use this kind of storage is where (( )) long period of time is the question that we need to answer answer now.

Now, to answer that we evolves several performance criteria, first level question is that at each of the reservoir has it mean able to meet the demands. We do all of this optimal storage zone and then operate according to the policy the release policy, transfer policy, the diversion policy etcetera.

We do that at each of the reservoirs in such a complex system. So, how does this system now, perform with respect to this optimal storage zones? Is the question that we need to ask? Do that we evolve performance criteria and the first level question that we ask is how reliable is the system? In terms of it is ability to meet the demands at each of the reservoirs and the system as the whole. The system as the whole has certain demands, has it mean able to meet those demands.

Then in the in the periods, in which it was unable to meet the demand at a particular reservoir, it has gone into failure state. How long that it is stay in the failure state? How quickly can it recover from failure? That is the (( )) then what is the effect of the failure itself? There all the deficit, but this deficit may have occurred at very critical time and therefore, the effect of the failure can be very large or there was a deficit, but it occurred in a such a period that it did not matter much in terms of the performances the system. So, what is the vulnerability or the effect of the failure itself? And what is the deficit ratio? How many times the reservoir levels went down went below certain (( )) value and so on.

So, these are the types of performances measure that we formulate there are large number of such performances measure, we will take 4 of them.

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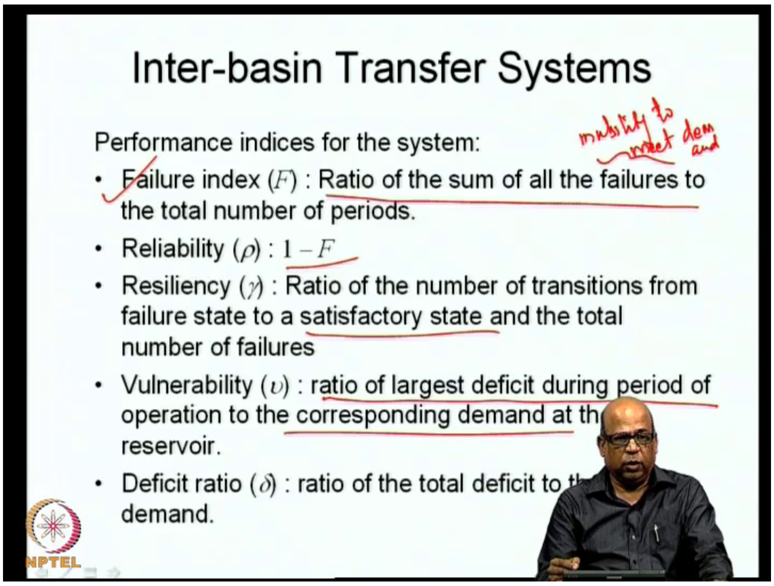

If at 5 will take, first is the failure index simply take the ratio of the sum of all the failures. Now, failures we may define variously, we will simply say that inability to meet the demand is the failure.

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Now, this can be aggregated demand or it can be separately for irrigation demand, hydro power demand and so on. Then we will call it as reliability that is 1 minus F, which is the ability to meet the demands, then resiliency, is as I said is the ability of the system to recover from a failure. This we compute as ratio of the number of transitions from failure state to a satisfactory state, divided by the total number of failures. This is how we calculate resiliency. Similarly, vulnerability in this particular problem, we define it as largest deficit that I occur divided by the corresponding demand and deficit ratio as the ratio of the total deficit to the total demand like this.

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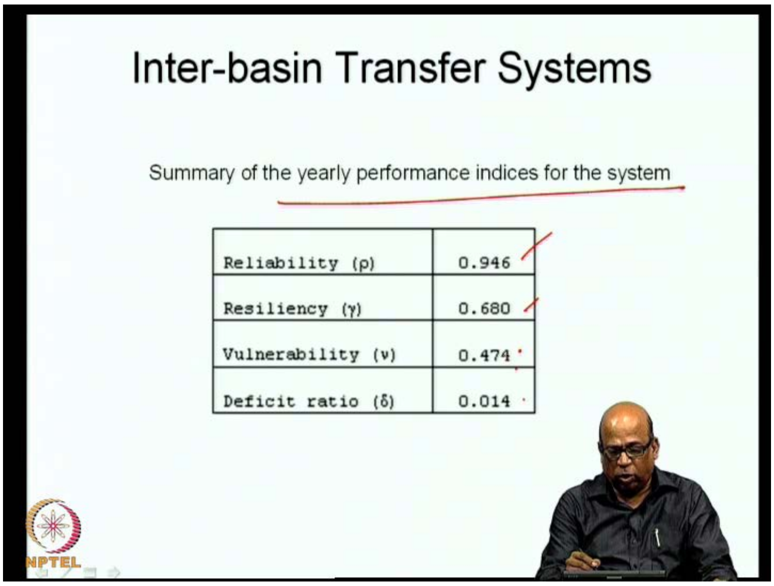

We define different performance measures and look at how the performance of the system has been. So, yearly performances of the entire system use something like this. we would like to have a system with high reliability as well as with a high resiliency, but low vulnerability and low deficit ratio in this particular case vulnerability is still quite large indicating that if a failure occurs the effect of the failure can be quite large.

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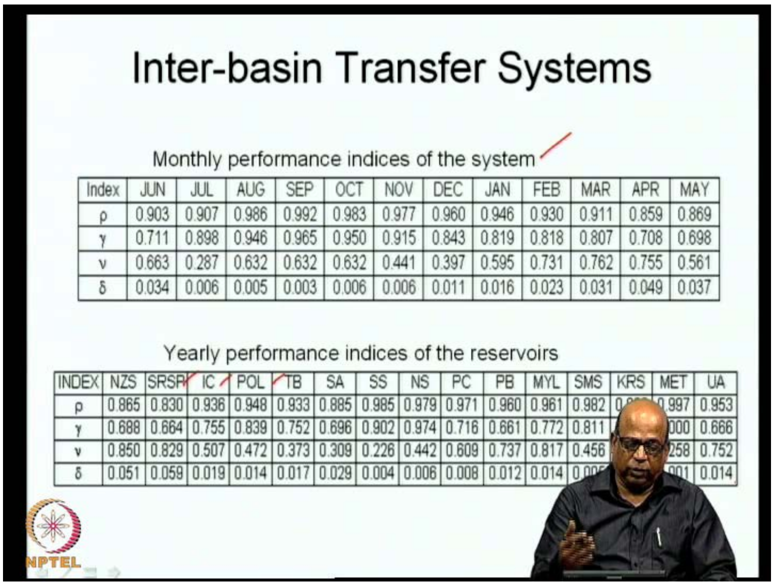

Similarly, we determined it for the monthly performances, then at each of the reservoirs. We look at each of the reservoirs how the system as performed? So, this is the use of the simulation model in the case of large systems. So, in the large systems first we build the simulation model and then put into an optimization model and look at how do we operate these large systems And how do we define storage zones at each of the reservoirs? Such that the system performs in a satisfactory manner and these are systems analysis model. Remember you do not apply this directly on to the field. These are systems analyzes models by which you can judge whether it is the transfers are possible to the extends transfers are possible and so on.

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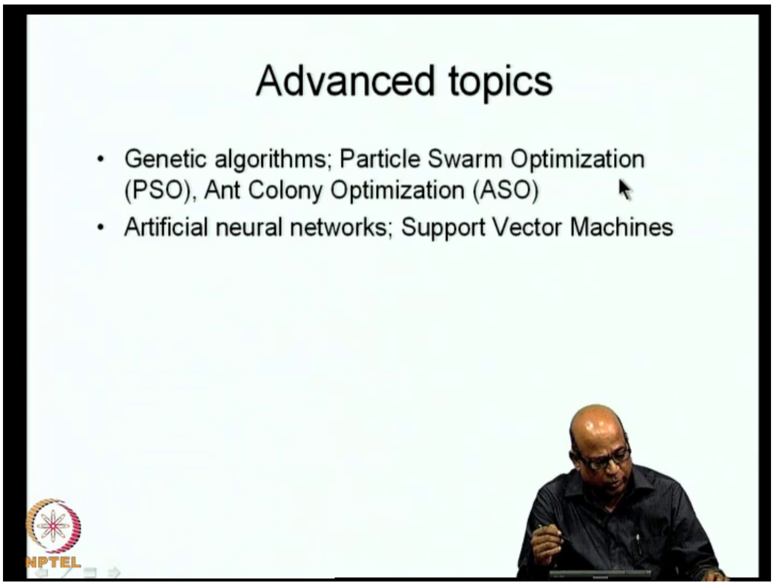

So, that in essence what I want to cover in this course, but these are preliminary techniques at we have learn for a new student. Essentially, we have learn in to this course, the techniques of system analysis starting with the classical optimization techniques, the linear programming, the dynamic programming and then we also look at the multi objective techniques, multi objective planning programs and then went on to the stochastic optimization techniques.

Typically, we covered the chance constraint linear programming and the stochastic dynamic programming and we also looked at the fuzzy optimization and the special specific applications that we dealt with or related to the reservoir operation, multi reservoir systems, the water quality control, then towards the end have also dealt with the conjunctives of surface and ground water hydro power optimization, crop yield optimization and today I discussed the inter-basin transfer of water. Transfers systems where we have large systems.

Now, these are the preliminary course of the water resource systems. There are several advanced topics in fact, as I mention towards the end of the last application the problems are extremely complex and therefore, you cannot put them simply in simple linear programming or simulation models and then say these are the optimal solutions.

You need to look at some advanced technique and these are some advanced topics that you can consider going through. For example, you may have Genetic algorithms, Particle swarm optimization, Ant colony optimization etcetera. These will provide you with better tools of optimization, then you have search you have pattern (( )) to such as Artificial neutral networks, Support vector machines etcetera. These you can use it for forecasting of flows, fore casting of the performances and so on.

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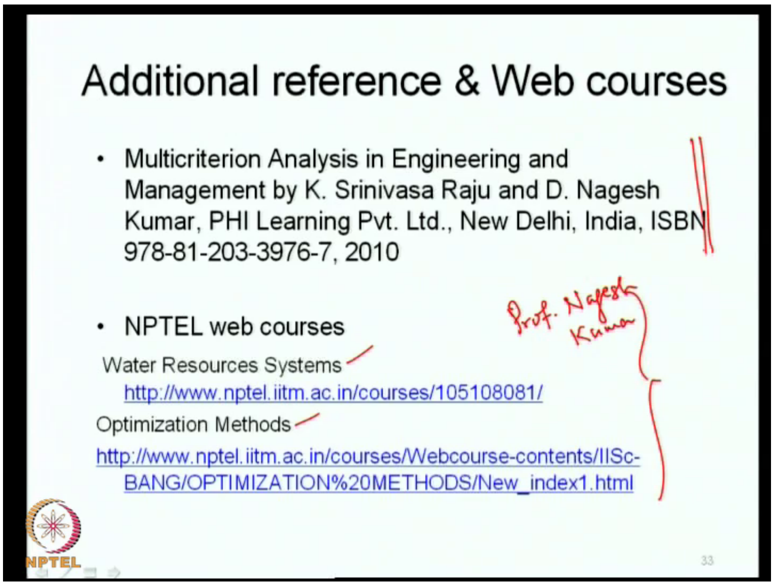

So, these are some advanced topics that the students can learn also we have some web courses already available on the NPTEL websites. So, you can refer to these web courses is both are by professor Nagesh Kumar of IIC you can just refer to these courses, one is on water resource system and another is on optimization methods both will be off use.

In addition there is a good book on multi criteria analysis by K.Srinivasa Raju and D. Nagesh Kumar.This also gives you good idea and exposure on several techniques of multi objective optimization. So, that completes the course portions at all for this course, before I end the course I would thank you NPTEL for this opportunity and specifically to Dipali Salokhe and Guru Prakasah for helping me in delivery in this course and to all my students, we have taken this course and help me learn along with them. So, thank you very much and all the best for you.