Susitna River ice discussion, by Tom Lavender
Exhibit E Symposium

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Transcript of

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Construction, Reservoir
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...nder, Acres
November 30, 1982

Susitna Hydroelectric Project.
FERC License Application Exhibit E
Presentation and Discussion

Holiday Inn Anchorage
Nov 29 - Dec 2 1982

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Presentation by Tom Lavender, Acres Consultants, Tuesday November 30, 1982

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This is a transcription of Tom Lavender's Susitna River ice discussion at the Exhibit E Symposium in December. A line (________) indicates word or words not intelligible from the tape of the talk. A question mark (?) indicates word is uncertain.

FYI

Bill Wilson ________

Mike Prewett MP

Paul Myer PRM

Ken Voos KV

Mike Kelly MK

no time now is this going to be in SUS?

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To do this I have prepared some cartoons to help explain principles. To give first here I have a representation more or less of a median flows one can expect in a river, the blue line indicates is the flow hydrograph for the present condition we can see to a year in a depth to signal (?) variation where we have summertime peak discharges passage of months declining to winter lows and then the spring rise again with period of particular interest to us in this discussion being the winter period beginning about this time mid-October and ending about this time and finish at breakup in mid- to late-May. These winter periods can be subdivided significantly in terms of freezeup period in the front here which now takes place between mid-October and mid-December, more or less, and the breakup period which occurs very fast in a short period from mid- to late-April to mid-May. Now, __________ the most significant effect of the project and with any storage project is the great re-regulation of the flow when the change in flow pattern in the river downstream. This of

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To do this I have prepared some cartoons to help explain principles. To give first here I have a representation more or less of a median flows one can expect in a river, the blue line indicates is the flow hydrograph for the present condition we can see to a year in a depth to signal (?) variation where we have summertime peak discharges passage of months declining to winter lows and then the spring rise again with period of particular interest to us in this discussion being the winter period beginning about this time mid-October and ending about this time and finish at breakup in mid- to late-May. These winter periods can be subdivided significantly in terms of freezeup period in the front here which now takes place between mid-October and mid-December, more or less, and the breakup period which occurs very fast in a short period from mid- to late-April to mid-May. Now, __________ the most significant effect of the project and with any storage project is the great re-regulation of the flow when the change in flow pattern in the river downstream. This of course is beneficial in terms of hydropower generation so the area under this hydrograph of course represents a _______________ so we see the red line would be indicated median pattern of flows throughout the year. We see of course that this is more or less constant throughout the year as compared to this very sharp peak and the volume of water indicated by the area between these two lines is quite simply transferred from the summer season to the winter season. The area here is equal to the area in here, representing a transfer _______________________ ________________ if its released in winter months. From the point of view of ice cover the most significant aspect of this is not the difference in discharge, increased winter discharge. The reason being the principal factor governing ice processes in the river is discharge, the principal factor concerning water levels, thickness of ice cover, and rate of development. ______ the other second effect consequence of the power regulation is its influence on temperature. We should discuss these to some extent. Here again I have indicated with a blue line this time a thermograph with the same period of months. The blue line indicates the natural condition where we see a summertime rise in temperature to about 9°C declining to a winter temperature 0° plus a fraction and so on year after year. With the project in place we will see some changes in these temperature regimes and as I have indicated here as the temperature is thermographed for a section a very short distance downstream of the project. With regulation we see higher wintertime temperatures, rising to a summertime here not as high as the natural conditions in the small difference there and declining more slowly in the fall as the influence of the reservoir retards the cooling down of the river and the thermal map _____________________ reaching ultimately some temperature which has been discussed and would be less than 4° greater than probably about 2°. I have a scene here for illustrative purposes, something about 3° during the winter months ________________ springtime to rise. This line corresponds to the regulated condition for, say, just a short distance downstream from the project. As you move downstream you see a decay in these temperatures so there is some distance downstream you would expect to see temperature profiles as indicated for example by the broken line here where the summertime temperatures are a little higher because heat gain between reservoir and that particular point and you would see some lag or delay in the time in which the temperature decayed to 0° but it does indeed get back to the natural level and would remain there during the winter at some point downstream. This is rather significant with respect to answering your questions for where the ice front is going to be located. I would like to make a very important point here which is that in looking at thermal effects we really should be looking at total(?) energy content. The temperature is nothing more than a manifestation of the amount of thermal energy that is present. We see in fact that what the reservoir does with thermal energy, it is normally gained in the summertime would be quite simply transferred to the wintertime just as it transfers runoff volume to the wintertime. So that if we look at incremental heat graph, if you like, this represents the amount of heat that is in the water at a given time of the year over and above what would be there under natural conditions. Which is to say, that if you take that volume flow rate difference multiplied by the corresponding temperature difference you can convert that into BTU's per hour or as I have used here megawatts, which represents heat content. You can see that during the winter months we have an excess amount of heat being released from the reservoir and it is rather significant, in terms of approximately 3500 to 4000 megawatts, a tremendous amount of thermal heat. Heat corresponding to that excess wintertime heat in the summer months even though the difference here is relatively small the discharge is large so that you see quite large negative heat content. That is, less heat from the downstream channel during the summer months or under natural conditions. And just as in the case of the reservoir where the volume (the area here and here must balance, and the area here and here must balance). Mean temperatures are unchanged and quite simply affected a transfer of thermal energy from summer months to winter months whose manifestation is temperature. You're really talking about thermal energy when you talk about temperature.

I have characterized here a typical hydroelectric power installation and tried to illustrate a couple of points with respect to the influence of this project on location of ice front. We know that the upper part of the diagram represented the river flowing into a reservoir, with a backwater unit somewhere up here. The reservoir and dam with power house and spillway downstream of that point in the unchanged natural channel. Under natural conditions winter flows are very small as we saw for the ________ in the winter and the water temperature is quite cool, specifically will form an ice cover throughout the whole reach downstream. A river like the Susitna River which is a steep river makes ______________________ an ice cover by the process of juxtaposition which I will describe later on, which is to say that it has to have enough ice produced on the surface by heat exchange in the form of frazil and ice pans and slush, snowfall ___________ to where there is an adequate amount that the river is covered from bank to bank, but once it's been covered and the blanket of slush that is moving down is thick enough and develops enough friction with the banks it will arrest a constriction in the river which is commonly referred to as a lodgment point. Under natural conditions with low flows and a very high rate of ice production you can expect lodgment points at various places along the river, for example as I have indicated here you might expect one with a configuration like this, or like this, or like this. Quite simply, ice is generated on the surface by cold weather and the slush rolls down to a point like this but cannot get past it, hangs up with bridges and it will form a float at this lodgment point. From that point, any one of these points under natural conditions, the ice cover can advance by juxtaposition and the rate of advance, then is a function of the climatic condition, the rate of which ice is being generated on the surface of the river. When we build a hydroelectric project and regulate the flows in the manner indicated here, there are quite significant changes made downstream at this point. First of all the dam cuts off the supply of any ice that is generated upstream to the lodgment point downstream. In the case of a power project the first lodgment point occurs under nature and appears, from our previous observations, to be quite regular, occurs quite close to the location of the proposed location of the dam. Which is to say the construction of the dam will not, _______________ the diversion condition when there are very little thermal effect. The construction of the dam will not affect the rate of ice production in the downstream region because there is by nature a lodgment which cuts off the supply of ice. Under the natural condition all the coverage which takes place downstream of the Watana takes place without the benefit of ice produced from upstream. The regulated flow increases the hydraulic forces and hydrodynamic forces that occur in this river so that it becomes more difficult, first of all the stage is higher so that the width of the river at the higher discharge is greater, like the span is greater and is harder for the ice to bridge. Commonly what happens with the high regulated winter flow at the time of freezeup is that these points are eliminated as lodgment points, even if they're well downstream of the point of thermal input from the reservoir. Quite simply because the hydraulic forces against which the cover must lodge are too high for it to lodge at that point. It will not be until they are some point well downstream where there is indeed a very severe restriction and well removed from any thermal effect that we get a high rate of slush production before you will have a lodgment point. The significance of this is that under natural conditions you can see that the lodgment point occurs there with the cover fairly early in the year and the cover can just advance from that position up the river whereas at the ________ point I have to start an appreciable distance downstream. You will not see a cover there till much later in the year for the simple reason that the ice, that the river can only produce so much ice, and __________ at a certain rate and the cover has to progress all the way from here and it takes longer to fill ___________________________. _____________________________________ it all has to become as one continuous process from the bottom end.

The consequences of thermal effects is that, as we have seen, the outflow temperatures from the project will lie somewhere between a maximum of 4° and a minimum of probably 1.5° between experience in Williston (?), depending on the conditions we talked about. We see an initial temperature condition here, a boundary condition, which has possible range lying somewhere in here. As I described in connection with downstream temperatures as you move downstream the channel you have heat exchange with the atmosphere through the open water surface and you see a loss of thermal energy and you see a decline in temperature in the downstream direction. The decline probably approaches 0 depends of course on the starting temperature. As you can see at some point downstream it will reach 1/10 degree C, in this case well downstream, in this case much closer to the project. From that point the significance of the .1°C that we have found from observations on other rivers, most notably the Peace River, that from the bulk water temperature, and this is the <u>bulk</u> water temperature, that down to about .1°C the temperature gradients within that bulk are such that you can begin forming ice on the surface of the river. You cannot possibly see any ice upstream at this point, the point of where this temperature is about .1°C. At that point the surface temperature is low enough that you begin to see ice form on the river. Beyond that point you will be developing ice to both the ice edge and the open water surface continue to ______________ to the atmosphere and will climb until you have enough ice that you have 100% coverage. You can understand that this position can move up and down the river under very, very cold conditions and can expect this transition point to move up the river as the more effective to the higher rate of heat loss from the surface. Under very mild conditions it would move downstream. There is never in any one season a particular point where this starts. It is moving on a daily basis depending on the current climate. The same thing applies to ________________ which you might ________________________ as a function of the current climatic conditions. Along this reach is partly dependent on the current climatic conditions and also on the distance through the point where the first lodgment can occur and how far the cover has been able to advance from the beginning, from the first lodgment ______________________. We have here a system where water containing thermal energy transferred from the summer months is released into the tail race. The thermal energy is transferred to the atmosphere when the temperature drops to about half a degree of bulk temperature, at which time it can start to generate ice, increasing growth rate, increasing the accumulation in downstream direction as it is feeding the ice front which is advancing by juxtaposition from this point __________________. You can see what happens here is the process will continue until the ice front will continue to move up in this direction till it reaches a point where it can advance no further for the simple reason that you cannot generate ice because the water temperatures are too hot. So you would never after ____________________________ you would never expect to see an ice cover upstream from that particular point, the location of which, remember, is dependent on the current climatic year so it would be a different position depending on how severe the winter is.

From the consequence of sort of pattern you can expect to see under both project conditions the variation in average winter air temperature, if you have a warm year the initial lodgment would take place a little later in the year and you would have the ice front advancing and the reference pointers from the lodgment point ________ with the passage of time and if you have indeed a warm year all through the winter then you would find that the ice front would not advance beyond some point here. Normally what happens is, as the ice front approaches the open water reach the rate at which ice can be supplied to the front is decreasing because that partial covered reach which is generating the reach is becoming smaller and smaller. You indeed see a deceleration in the rate at which the front advances. The other thing is that this quite commonly occurs towards the end of winter when you are beginning to see a winter warming trend. The other extreme if you had a cold year all the way through you would see a somewhat earlier lodgment date, somewhat faster rate of advance, and you would finish up with the cover advancing a further distance upstream. In reality, this never happens because you never get, very rarely get, a pure year in terms of being warm or cold. You sometimes have a warm fall and then a very cold mid-winter in which case you depart from the warm lines to somewhere on the _________. Typically, if you plot a _____________ ice front position as a function of calendar date, you are _________________________ for a given year you find that they wander all over the place but you stay within a band which you can define in terms of a cold year and warm year _________________. The most significant thing about this is that we are looking at a process that is by nature very variable. You have this sort of variation even under natural conditions as a consequence of variation in climatic conditions.

Now I'd like to discuss the ____.
That's the end of my discussion on the effects of the hydro project on where the ice front is going to be located and which reaches of the river would be covered. We will move on now to the issue of changes in water levels. In order to understand some of the subsequent diagrams I think it is helpful to have a bit of the notion of the complex of juxtaposition and the meaning of leading edge stability. As I described previously, normally what happens is that open water surface or heat exchange develops frazil ice and slush ice in the form of _______________ flow down the river to some point and if there is enough of these they will lodge at some point downstream. And from that point the cover will advance by the process called juxtaposition, upstream. It will reach periodically a particular cross-section which is more difficult for the cover to develop past than any other area and I have indicated this very clearly by _______________ photography here. What happens is that the cover will advance quite happily by juxtaposition to a feature such as this and then it cannot go any further for the simple reason there is a piece of pan or cake of ice in here butts up against this end on the water surface, it cannot stay there because the velocities are too high. Hydrodynamic forces cause it to submerge and be carried downstream. It will be carried downstream to the first position where the velocity in the stream is low enough that it can stay there and it will deposit in just exactly the same manner as the sediment process in the alluvial fan of a river if the whole thing is upside down. It is an inverted alluvial fan made up of ice. And it will keep depositing at that point until the velocity increases to a critical value and ______________________________________. Under freezeup conditions this has

been observed to be in the neighborhood of about three feet per second. Quite typically you have a deposit here until the velocity is increased a few feet per second at which time the incoming ice at this leading edge cannot stay there and whole process moves downstream gradually filling in the downstream channel. It continues to do that until such time that the additional hydraulic losses, because of the higher velocities on it, are such that you get a backwater effect which in essence swings the ice cover up and drowns this constriction. Stream raises(?) it until the water level reaches a critical level which can be defined in terms of what is referred to as leading edge Froude stability number. Froude number is defined in these terms as velocity divided by the square root of dh, where h is the depth at that particular point. It can be expressed in terms of ___________ discharge quite simply in this way and if we rearrange this thing and solve for the critical depth we find that we can express it in terms of constants, which includes some critical value in Froude numbers and the specific discharge or discharge per unit with the channels to 2/3 power. This is an extremely useful expression. When enough staging has taken place here, when the backwater effect with these depositions is sufficient that you exceed the critical level; I have indicated the critical H and depth of depth by the red line through here. I have indicated here a situation where it is ____ stage quite enough to get out to the maximum level. The deposition will continue in this case until the water level is just at that point, then the incoming pieces of ice would stay at the leading edge and the process of juxtaposition would continue thereby increasing ice comes up and butts against the distal cover and stays in place and it graduallv progresses in the upstream direction. The key thing here is this critical value as indicated by the red line here. You can calculate this for any section if you know the cross-section data. Conversely, if you have an amount of field observations you can define this relationship empirically and you'll find that this value a critical value of H as expressed in terms of Froude number, or critical Froude number, will be such that the Froude number is always between the value of .154 and .08.

On that basis we can define what appear like rating curves and they are in fact a temporary or transient rating curve. I have indicated on here this discharge factor which is quite simply the discharge divided by the channel width to the 2/3 power which conveniently linearizes the equation that was in a previous viewgraph. I have indicated here an upper limit with a Froude number of .08 and a lower limit of .154. This number has been established on a theoretical basis. This number has been been established on an empirical basis, both in laboratory tests and in field observations and is extremely well documented. As also indicated on here, the open water rating curve which is to say the relationship between discharge and water surface level. We have a particular discharge that is described by this factor. You would expect to see a particular stage corresponding to that. This represents the water level that would prevail for a given discharge given that there is no ice present in the river. These two red lines represent the range in possibilities that would direct the water level the range in water level will be required in order for the cover to be able to advance by juxtaposition. It will not advance for a given discharge until the water level, in a case like this you have at the time of freezeup a discharge in this range before the ice front gets to your section of interest you will see it over both the water level like this. As the ice cover approaches there will be a backwater effect from it, water level will increase. The increase will continue until you would be on this line, but not higher than that line. So under freezeup conditions, depending entirely on the nature of the inflowing ice, can generally be described in terms of velocity and depends on the shape, size, density, strength of the pieces that are coming in. You will always have on the Susitna type of river an increase in stage where the open water condition to a minimum value indicated by this and a maximum value indicated by this upper line before the ice cover can advance. You can see that under natural conditions when winter discharges are down in the range of 1,000, say maybe 900 to 1600 or 1700 CFS, on the Susitna River when freezeup occurs you would be laid back in this region here. Under that flow condition you would expect the water level in the mainstem, corresponding to the blue line, _______________ advance increase to some position here. So if the regulated flow, the increase in discharge, is something in the range 8,000 to 12,000 CFS you would of course be causing freezeup to occur at some position over here. Your open water stage at the time of freezeup would be higher and the amount of additional staging is not as far as the leading edge stability __________ there, and will increase to something between here and here. To illustrate this I have an overlay here assuming that in this particular year the freezeup is a condition of the ice, so feeding the front requires that they be on the upper limit. We see for a natural freezeup discharge they start at a level like this and you would end up with a level like this. The regulated discharge would start at a level like this, appreciably above that level. You would advance to a level up here. When there is a change in water surface level in the presence of an ice cover it would be something like this. Now in the case of the Susitna River, this difference at Talkeetna is going to be about 4 feet and out in the Sherman area is going to be about 3 feet. If however you have a condition that you are upstream of the point of 0.1 .01°C water, i.e., in a reach where an ice cover can never form because of the thermal effects, then you would in fact anticipate an open water condition throughout the entire winter. Whereas under the natural regulated flow you would have seen a stage from this level to that level, under the regulated flow where the ice cover cannot occur because of the thermal effects you would see quite simply an open water stage and there would in fact be a slight decrease in water level in that particular reach of the ice-free reach. On the Susitna River it appears that this is going to be about a foot, or less than a foot. And of course there is a range of possibilities; I have one over there to indicate that. If in fact in a particular year the ice conditions were such that we didn't have to stay to the upper line in order to get an ice cover to advance you would see that there is a little difference in here. In this case under the natural flow you would see a very small stage increase __________________________. Under the regulated flow an ice cover at this section you would have an increase here smaller than the previous one indicated and if you in fact were in the open water reach you would see higher open water levels than would have occurred under the natural discharge with staging ______________. Where there is a wide range of possibilities depending on the particular ice condition at the time of formation in a particular year where there would be an ice cover you can expect increases in stage, when there will not be an ice cover there may be a small decrease in ______________________________ stage.

So that defines the water levels that you can expect at the freezeup condition. Now this condition applies only temporarily. It will only maybe satisfied at the period of time that the ice front is advancing through that particular reach. Once the ice front has advanced through, different things can happen. You referred to a uniform flow situation and to what the level control goes back to the question of channel geometry and channel friction. This condition no longer applies. However, this condition after freezeup determines what your prevailing winter water levels are going to be for a given discharge during the rest of the winter. To show this I have prepared another diagram here on the same basis. I'll just put it on here long enough to show you that I am taking off this particular line ______________________ __________________. For the moment I'm ignoring this possibility which remains unsolved. You can see as I have indicated; let's suppose that a natural freezeup discharge is 2_1 in which case you would be at this point on the scale of 10 and the freezeup level required, given in this ice condition at the time of freezeup, would require a stage of that amount. Once the cover is established it has a certain thickness which is determined by the hydraulic forces prevailing at that discharge. And that thickness prevails for the rest of the winter. Now it can in fact change. If it happens to be very thin relative to the thickness required for thermal equilibrium through the ice cover, that is, equilibrium in the heat exchanged from the river to the ice cover and the ice cover to the atmosphere, then it will grow thermally. If it is thicker than is required in terms of equilibrium then it can now become thinner. Right after formation, essentially you have a fixed ice cover and you have it fixed on a point on a rating curves where you revert to the uniform flow and you in fact then, the discharge varies around that, you would follow a rating curve which is more or less parallel to the open water rating curve that has been fixed for the winter or at least for the next short period of time by this freezeup condition. Then your rating curve comes through along the line like this. So if you had an increase to 4 say, or to 5, having closed in at this discharge the maximum level you would see would be indicated by a point up here.

--- Hiatus between tapes ---

... we revert to uniform flow ____________ control the rating curve we are following will begin more or less parallel to the open water curve and is at much higher level. Then we would experience a value of up to (?) 5 we can see a water level appreciably higher than those that had been at lower discharge. For the winter water level regime is fixed by the discharge that occurs at the time of the ice front advance through a particular region. Now this is all very idealistic principally for the reason that I have indicated because quite often the _____________________ adjustment in the ice cover, that you would have quite uniform growth in the thickness of the cover with the passage of winter ______________________, then you would gradually move from the rating curve upwards. If on the other hand you have thinning, or for example in this present year when you get considerable thinning, you're used to the water underneath warming up, then the rating curve would be moving down on this scale. Generally speaking, the adjustment that takes place on an ice cover on the Susitna River would be such that you'll always be moving down on this scale. The actual curve that you're on any time subsequent to freezeup depends on what readjustments ________ would come _____________ cover and in general would be moving down.

Under the breakup condition, when the cover has fragmented an advance is transported downstream by the flow of the increasing discharge; the whole process of staging to satisfy Froude criteria is again applicable. ___________________. Under natural conditions this occurs usually at a much higher discharge. So if you like, spring breakup follows sustained laws of mechanics to satisfy equilibrium of forces of equilibrium at the leading edge in the same diagram applied. But, generally speaking, I did not show this subject under natural conditions that occurs at a higher discharge and you're operating at some condition up here. The same process governs spring breakup water levels. There is, however, in the spring a limit to the worst thing that can happen to you. For example, you can envision a very high discharge that could put you out in a domain here ________________________ give you very, very high discharges. In fact this doesn't occur because you have a limiting factor, there appears to be a limiting factor, and that is the volume of ice that is available to form jams. Under the freezeup condition you have, for all practical purposes, an infinite supply of ice available to you as long as the winter lasts long enough. It just keeps churning away generating ice and feeding the front so that it has enough volume to be able to raise the water level for it to advance. Under the spring condition there is in fact a limit to the volume of ice available to you and that is limited to extreme physical limits than would have by these water surface area upstream of the point and in fact is generally limited by a combination of __________ and the amount melting that has taken place subsequently in the beginning of spring breakup. So you can, in fact, as a function of spring breakup ice volume, you find an upper limit on what can happen to you that's as good as your family of curves (?) for an increase in volume. What happens is that even if you get this discharge there is not enough ice available to effectively get the cover thick enough through hydraulic losses large enough to increase the stage to satisfy the leading edge Froude criteria; we just cannot get to this line or not even to this line. You can in fact define a limit here and it in fact defines the point of intersection __________________ physical upper limits are highly improbable at the 1:100 year volume because we find a critical discharge which is the worst thing that could happen to you, the worst level you would ever see would be something defined by this point of intersection. That deals with water levels at freezeup mid-winter and during breakup.

We will move on now to talk about ice thickness. We mentioned the ice cover thickness is also determined in large measure by the discharge at freeze-up. I don't have calculations for the Susitna River. I brought some for some that I have done on a reach of the Peace River to quite simply illustrate the influence the discharge has on the ice cover profile that can form. We can see in the upper diagram the ice cover thickness has been calculated using an ice program for discharge of 500 cubic meters per second (17,660 cfs). The cover has formed here by the process that we described meeting a stability requirement and it has required a certain thickness to get sufficient hydraulic mean depth at a critical point right here. This happens to be the controlling section. Once we have reached that the cover can advance very easy through here until your velocity gets ~~to~~ too high again and then go through the whole process. It is significant then as you can see for this 500 cubic meters per second that requires a certain thickness of ice. Under 1000 cubic meters per second you can see that the ice cover required to achieve that same thing is somewhat thicker and it has, because of the nonuniformity of channel geometry, you have considerable variation in shape of this ___________. And at the higher discharge you can see that it has one hell of a time getting through this section. It required an appreciable thickness here to keep the water level up. Plus it does because of the velocity in this pond (?) created by the reduction in conveyance of __________________ mass of ice, the velocities are so low that the ice cover can advance quite a distance upstream, quite slowly. The point is that the thickness of the ice cover that is going to prevail for the winter is determined in large measure also by the discharge that occurs at the time of freezeup.

The last item then was with respect to what happens to an ice cover once its established; if you change the discharge. If you freeze in at a very low level and very small discharge you can see you have a very thin cover. If you increase the discharge very markedly right after that is formed and very weak, you can ______________________________________ on the Peace River that cover is unable to withstand the high to dry forces at a high discharge. It collapses and you have in effect spring breakup in the freezeup period. The cover will reform at the higher level in accordance with the diagram, the leading edge stability requirement as I've indicated. However, it need not be that you precipitate a breakup of a cover like that every time you change the discharge because the ice cover generally when given a chance will develop an ability to tolerate rather large level changes as a consequence of variations in flow. There are two types of things that happen. The second one I will be discussing is actually a limited case for this. In the case where you form a very strong, thin cover, gives it a chance to develop considerable strength. If you exercise the cover it will form an articulated hinge along the shoreline. It requires a minimum of 3 fractures which would parallel the shoreline, and here where you have contact with the bank with its first piece, one a little offshore and one further offshore. As the discharge increases, the water level rises, the central part of the cover just quite simply follows the water level, and as long as you maintain contact at these hinge points the cover will follow quite happily without breaking up. You get the hydrostatic level over here and over flooding, and in fact you get both ____________________ channel. These can tolerate quite appreciable increases and one example in the Gatineau River, which is between two power plants that are operated by Hydro Quebec, and that little sucker can tolerate 2½ feet of change and never lose that contact. The other type of limited case is contact between ________ is quite typified by rivers in western Canada and Alberta and the Rocky Mountains. Their class of river is very comparable in some respects to certain regions in the Susitna River. The process of formation is as I described by juxtaposition you form the ____________________ between covers. That this is a wide channel in terms of the ability of the ice to expand the river reach. Subsequent to the formation of the advancing cover upstream would be a collapse and telescoping of the separate part of the cover and it will develop a shear line establishing grounded regions on the banks which would become the new river banks. Subsequent to telescoping and a certain amount of squeezing, the disparity would now be ____________________. The cover will settle down in between these grounded ice banks and in effect the channel is now defined by these. You don't see this happening on, I have not seen this anywhere on the Susitna River. There is some telescoping in certain reaches both particularly in the reach 5 or 6 miles downstream from the canyon. There is not a tremendous amount of this type of process taking place in the Susitna River for any length. Subsequently, if you decrease the flows to very low values the central part of the cover will quite simply float down. As it floats down it will develop fractures in the same manner as we have articulated. Then the pieces will quite simply lie in the river bed. When the water level comes back up if it hasn't been down too long, and sometimes if it hasn't refractured, the pieces will all float back up into place quite happily to retain the bank contact between the central pieces of ice and the shoreline and will all then stay in place very happily, and it will stay there and follow the water level. In springtime ____________________________________ flow, discharge is higher than the freezeup discharge and it will in fact float the ice cover up to the bank without flooding of the overbank areas as long as that cover retains contact with the grounded ice on the side here will stay in place and not fracture. As soon as the discharge is such that stage comes up and ruptures ________________________________ the whole cover will collapse _________ which is the breakup. I don't have slides of these processes. I do have four photographs which I'll pass around indicating this sort of thing. The top one is Hollingsworth Reservoir which belongs to Great Lakes Power in northern Ontario. It is a little reservoir but in this instance we've drawn down 30 feet in order to effect repairs in the intake structure. It was subsequently brought back up 20 feet and you will see when you get a close look at it the pattern of fractures that occur along the ice cover as the water level is brought down. You will see an area that has been flooded, corresponding to an articulated-type hinge, quite typical of this sort of thing which you can expect a major drawdown on an ice cover in place. The second photograph is from Jakineau (?) River which I mentioned which is a very fine example of the articulated hinge. This is the one that Quebec Hydro has exercised in experiment, to the extent of 2½ meters of vertical variation. The third photograph illustrates the type of hinging that takes place on the Peace River, and here's a section of the Peace River near _______________. And you can see along the shoreline the overcrowding has taken place as the cover has been exercised all operations near _______________ upstream. The cover stays quite happily in place following the water levels. The lower diagram is also a Peace River further downstream and it shows the last condition I had on the slide here of overflooding of the bank has occurred in this condition here. Overflooding of the banks has occurred but there is still bank contact and the cover still stays quite happily in place.

Fire away, gentlemen.

Q: Tom, would you elaborate a little on the breakup process downstream of Talkeetna if we have during the wintertime twice the flow that we presently have, let's say at Susitna Station, therefore there is going to be a substantial amount of ice increase, and during existing conditions, could you explain how what could possibly happen with ice jamming during the springtime.

A: There are two things that happen here. First of all, its important to note with respect to the change in flow that under the breakup conditions the regulated flow is appreciably less than particularly at the later beginning of the breakup period. The regulated flow is appreciably less than the natural flow. This is significant in terms of the staging required to satisfy the Froude leading edges stability criteria. In terms of this diagram, under the natural conditions you can expect breakup for that reach to occur somewhere in here which means that you would expect to see a high discharge as high breakup levels. Under the regulated condition you will unlikely ever see discharges that high again and will in fact be very close to the regulated flow which will bring you back down here somewhere. Now there is a very clear benefit to flood control in the lower reaches as a consequence of production of spring flows at the time of breakup. The other factor is a question ________________. We will indeed be more ice in the river as a consequence of the development of cover at higher levels. Now that becomes relatively minor significance for the simple reason that it only takes a certain volume of ice at the discharge to establish the critical Froude level. It takes a certain volume of ice in this area to produce the hydraulic constriction to stage to the critical Froude level at this point. So the question is not necessarily ...; the fact that you have more ice is not necessarily of significance because if under natural conditions you have enough ice to stage to that level under the reduced spring discharge due to regulation, if natural conditions would provide that volume of ice it is irrelevant that you have more because all it means is that the stage will go to that same level here and you will have a longer extension of the ice cover upstream because there is more ice under that condition. The general consequence is that the benefit of reduced discharges far outweighs the difference in volume of ice.

Q: Okay, you're going real fast here. I'm going to have to slow you down because I'm a little slow. I want to ask several questions. First of all, let's take at Su Station, way down river. During winter flows of regulated flow, if my memory serves me, we're going to have approximately double the normal discharge on a normal year as we do with no hydro dam and no regulated flow. True or false?

A: True.

Q: Okay, so we have twice as much water during a regulated time and this exercise you just put us through, which I found very informative, was that that tells me that we will probably have a lot more ice formation in that lower part of the river. Right? Because of the physics it takes to do that. We're certainly going to be below natural temperature, you know, a type of thermal effect from the hydroplant down that far, but we're going to twice as much water in the system so it seems to me that we're going to have a lot more ice down there than we normally would.

A: Because of the thicker cover you will you have more ice.

Q: Right, okay. Now, during breakup, you're saying the regulated flow is going to be very important but if you go back to the initial stuff we're looking at during those months when you start to get your breakup the effect of the discharge from the Susitna portion that is coming from the reservoir is a pretty small percentage of the actual discharge of that system. Because you've got the Yentna and the rest of your systems dumping in. What effect is that going to have with all that normally very high discharge on a lot more ice we're going to have down in that system. I'm really concerned about that.

A: One of the consequences through the compensating effect for the greater thickness and the greater volume of ice under the regulated condition, and that is the heat content of the reservoir. The water temperatures in the Susitna will rise because they have never gone down to 0, they will be warmer earlier in the season. The consequence of this is that, with the regulated flows, you tend to get a very rapid rate of melting erosion of the ice cover. So it disappears very quickly.

Q: So you're saying that even down below the confluence of the Talkeetna and the Yentna and these areas we're going to have, with a regulated flow in the wintertime or in the fall and starting in the winter, a lot more water than normal, that when the source breakup in the spring that there's going to be enough temperature naturally that its not going to make any difference?

A: I'm not saying that its not going to make any difference. I'm saying there is a complicating effect.

Q: Well, would you expect that for downstream, Tom, that there would be any residual impact from the reservoir temperature?

A: Yeah, I just realized that I have (goofed up), just making a point as I went through here (let me find my diagram). Under the freezeup conditions here, I'm going back to freezeup conditions to give you some feel for the extent of this open water bit. I don't have any calculations to be able to talk specifically about the breakup. Under freezeup conditions, if this is with Watana only, operating and the outflow temperature here is 4°C, then this location is about Sherman. If this is Watana and the outflow temperature here is 2° then this is about downstream of Devil Canyon, Quartz Creek. If this is Devils Canyon and the outflow temperature is 4°, this is downstream of Talkeetna. If this is Devils Canyon and this is 2°, then this is about Sherman. Now this is under the freezeup condition where you have net heat loss through this reach. Under the spring condition we were coming out at some temperature in this range and will be adding heat here starting from base level not at 0 but from a base level significantly above. This open water reach, the temperature defined here, and is quite sensitive to freezing temperatures, and both particularly where you have a net heat gain instead of a net heat loss. You would see temperatures rising around this point. Under breakup condition the temperatures here would be, instead of this declining this way, they would be growing this way. And in light of the tremendous amount of heat, even though it is low grade heat, a tremendous amount of heat is available ________ these covers. Specifically, on the Peace River downstream of Williston Lake, whereas under natural conditions they used to have spring breakup ice jam problems in the town of Peace River. As a consequence of ice breakup on the mainstem of the Peace River and a major tributary just upstream of the town of Smoky River, what happens now typically is that the mainstem river ice is long gone because of this spring thermal effect before the Smoky breaks and you now have a much smaller total volume of ice available to cause flooding in the town of Peace River under the regulated condition.

Q: I'm having no problem with what you're discussing right there and I do understand that. I was wondering basically where you're talking about open water and ice coverage. That wasn't exactly my point but that's okay, I want to ask you a couple other things. And that is, when you were discussing what it took for the ice buildup by the juxtaposition and you do need basically, it increases the level of the river to do so, we're talking in the terms of even 12,000 CFS and, just for arguments sake, let's say one of the sloughs that Woody was working on in that area where 12,000 might potentially be that point where the upstream berm would keep water from going through, or 11,000 or whatever. What happens then when we get this buildup, depending on the temperature, and as the ice moves forward you need the increased water level, it floods over into these slough areas you wouldn't normally flood during that time of year.

A: I don't know. That depends on the elevation of the berm end of the slough.

Q: I'm just trying to say, just theoretically, I'm trying to be as theoretical here as you are.

A: That's right. That's fine. You raise that possibility. That has to be determined on a slough by slough basis. The next step beyond this is to run a backwater calculation with the ice cover in the position where you are not going to go and at the thickness that you're going to form at. The calculations require starting from this point to exactly the same type, we're saying that,

____________ on Susitna I used the Peace River example. So, if you knew what you're freezeup flow is you can calculate, as we've done here in an ice profile that you would expect the consequence of that flow. Then, having that established you can do full calculations with HEC 2 in order to get water surface profiles which gives you the water levels for each specific point. Now, in this particular case we were doing this because there is a flooding problem in west Peace River and we have flood dikes in place the elevation of the crest which is indicated here. I'm quite concerned about whether winter levels under power regulation will exceed these levels or not. Exactly the same problem in hydraulic terms as the slough problem. You would have to do this sort of analysis on the Susitna River and then find a particular berm location for a particular slough you have to know what that elevation is and relate it to the berm elevation. If its higher than flood, or lower than flood.

Q: Just one more point. From what I'm gathering then and what you tried to relate to me here a couple of minutes ago, am I to assume that the increase regulated flow downstream, even from Talkeetna, even down into say to the Yentna, will not have any appreciable effect on the ice cover or the consequences of breakup due to regulated flow, just by the basic physics that its going to take to change ice cover and the flow its going to take to discharge it. Is that true or not?

A: I carefully avoided saying exactly what those changes are. What I've tried to do here is to give you some understanding ......

Q: Okay I know, but I'm asking a pertinent question. Can you give me an answer or no.

A: There will be changes of the type I've indicated. The magnitude I don't know. It will be less because the gradient of the river will be the determinant of all these things; the slope of the river. As the slope is decreasing in the downstream direction, i.e., the flatter the river slope less severe in this effect.

Q: Okay, that's fine, that's good.

Q: You don't know at this point even if ice is going to form downstream of Devils Canyon all the way to Talkeetna, anywhere within that entire reach, or it may not?

A: It's going to depend on the type of climatic conditions of a given year as they influence the reservoir temperature and as they influence the heat exchange in the river, downstream from the reservoir.

Q: What about, can you put some numbers on these elevations, on the stage elevations?

A: Yeah, in the Talkeetna area you can expect a stage increase of about 4 feet and at the Sherman area an increase of about 3 feet.

Q: That translates, the equivalent open water flow would be substantial under those increased stages. You can just look at any of the cross sections that I showed for example this morning and look at what 3 feet will do and some preliminary, we haven't run the HEC backwater program with ice cover for the conditions what we've just been discussing, but we looked at it by inspection and if the ice cover proceeds upstream of some of these sloughs there is absolutely going to be overtopping. Unquestionably. Flow is going to go up through the slough.

Q: Does that have any influence on sediment transport or armoring or any movement of materials within the sloughs especially within the mainstem?

A: It can do. Under the ice cover condition. I'm not sure what this river is, and I'm not familiar with the morphology of the ____________________ to take velocities of this sort of calculation describing this. One of the things you get out of this sort of calculation is the velocities in the area when you make an assessment then what is going to happen to the bed of the river. There are two limiting velocities, two limiting conditions under ice cover which determine whether you get bed scour or not. I mentioned the limiting velocity under the equilibrium deposition velocity or erosion velocity here of about 3 feet per second. Under formation condition we have never seen velocities in excess of 3 feet per second. So under this formation condition if the bed of the river is paved with cobbles that will resist that sort of velocity then the bed will not be disturbed by the fact that you have graded ice thickness at a higher freezeup discharge condition. If the bed material is such that it will be eroded by the velocities it means that that is occurring right now in the river as a normal annual consequence and is going to continue in the future. For example, in ________ channel in the downriver in Toronto, Ontario the variance __________ because the bed of the channel is where most of the ice jam takes place is very fine material. The ice jam, ice responds to flows under it and the ice just keeps following ___________ scour holes. The same thing applies downstream of Muskrat Falls in the Churchill River in Labrador, a 150-foot-deep scour hole downstream of Muskrat Falls because the bed resistance is lower than the ice resistance. The dam just keeps pumping ice from the falls downstream in this manner and it just keeps, the velocity increases the _________ load, more ice deposits than this ___________________________________. The critical question here is, under formation conditions, what is the present state of the bed. Will it resist ________________ velocities or not. If it will, it shouldn't change _______________ then you can see erosion but you should be seeing erosion anyway under natural conditions. Under breakup where you can get, the process with respect to this is the same as the process whereby you get the staging, its quite clear in the summer these are quite different. You will get an abrupt breakup of an ice cover with a mass of ice moving down the river to a point where it comes against a solid piece of ice at rest. They will all jam in and, instead of having this gradual deposition process taking place all the way down the river, you just quite simply form a hanging dam and get tremendous resistance. There have never been direct measurements of those velocities for the simple reason that I haven't been able to find a sucker to go out on an ice jam that I'm familiar with. (laugh track) We have inferred velocities from calibration of our ice mechanics model which suggests that under that condition we may have short term velocities under an ice jam in the area of 9 or 10 feet per second, or about 3 meters per second, so those are not direct measurements, they are inferred and we don't know how good they are. But again, if you are getting that sort of jamming condition which you will on the Susitna in two or three places under spring breakup discharges you can expect to see those sort of velocities under natural conditions. I understand from the conversations with the people here that there have been quite a readjustment to some of the river cross-sections since the last survey as a consequence of the rather large spring breakup discharge this year. And that is probably ___________________________ area you get those high velocities and it takes quite an appreciable cobble or boulder to resist 10 feet per second, so even under the natural process you are getting that sort of breakup velocity from that sort of readjustment of the bed. We would not expect the net velocities to change by the fact that you are regulating the flow. In the Susitna River itself, you would be less likely to form that sort of jam because of the heat content and greater information ____________ the cover in place because you are limiting the maximum discharge under normal power flows ________________ the sort of event that occurs by nature ______________. You would expect to see those 10 foot per second velocities under ice jams less frequently after the project.

Q: Can we talk about fish for awhile, I'm getting a headache? (laugh track)