Review of the 2005 Environmental Water Account Workshop

by

James Anderson

University of Washington

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Introduction

Because the Environmental Water Account is a program to alter flows and water exports from the Delta, the focus has been to assess the impacts of these actions on species of concern: salmon and Delta smelt. For salmon the major effort has been directed toward quantifying the impacts of water exports and river flows on survival thorough the Delta Action 8 experiment for Sacramento salmon, and through the Vernalis Adaptive Management Experiment for San Joaquin salmon. For Delta smelt, the focus has been directed toward the impacts of exports on take of the pumps, and to the more subtle impacts of water operations on critical life history stages of smelt and other resident fish in the Delta. The interactions of Delta water action on pelagic resident species is a far more complex and difficult problem than their impacts on salmon migration.

It should be kept in mind that the original intent of the EWA was to reduce fish take at the pumps, in particular the take of salmon. At the initiation of the EWA it was believed that a significant fraction of the migrating populations were lost in water exports; fish managers rightly took measures to limit exports when juvenile salmon species migrated through the Delta. To reduce take, the EWA program used a two-pronged approach. First, water resources were purchased which allowed some reductions of water exports when fish were migrating, while at the same time insuring the supply and quality of water to agricultural and municipal users. The second approach was to evaluate the impacts of the EWA actions on fish, and with this knowledge improve the allocation of water resources. As documented in EWA Panel reviews between 2001 and 2004, many parts of this program were successful: water supplies to users were maintained and much was learned about the effects of water actions on fish survival. Progress in understanding how water actions affect the Delta ecosystem has been slower, in part because of the difficulties of ecosystem studies and in part because the EWA research has not focused on identifying ecological mechanisms by which water actions affect the species of concern.

EWA research on salmon has been significant in several areas. First, and most significant, the juvenile production estimate (JPE) that quantifies the number of juvenile salmon migrating from the Sacramento River was reevaluated and improved. Consequently, the take at the pumps was found to be considerably lower than previously estimated; as a result fewer EWA assets are now used for salmon. This is a clear success story of adaptive management. Actions were taken, research was conducted on the impacts of the actions, and, based on the research, the program was revised.

A secondary accomplishment of the research was to quantify relationships between flow/exports and pump take and smolt survival. Sacramento River juvenile salmon migrating through the inner Delta survive at a lower rate than fish migrating through the main channel of the river. Again, this finding was used adaptively, and the Delta Cross Channel operations were changed to minimize the passage of fish into the inner Delta through the DCC. However, the physical and ecological dynamics of the Delta limit success of DCC operations. The DCC closers must be restricted because the action contributes to the movement of higher saline water into the Delta. Furthermore, fish can enter the Delta through Georgiana Slough.

This interaction between the DCC operations, fish routing and water quality illustrates the need to understand and manage the resource from an ecosystem perspective. For salmon, the challenge is to inhibit both fish and salt from the inner Delta while conveying Sacramento River water across the Delta to the pumps. From an ecosystem perspective, water, salt and fish move in distinct but coupled dynamics: close the DCC to keep fish out of the Delta and salt goes in the Delta. Transfers of water across the Delta affect the distributions and life histories of resident species and take at the pumps. The distribution of salt affects the ecology of Suisun Bay, which in turn affects the life histories of other species. These ecological interactions are complex, and the impacts of EWA actions on them are poorly understood. The EWA Panels (EWA Review Panel 2001 and subsequent years) have consistently indicated the need to understand these interactions; the significant changes in Delta populations over the past several years only make the need for an ecosystem focus more important.

In perspective, the EWA program has accomplished many of the goals set out by the designers of the program and the EWA Review Panel. Especially with regards to salmon, the allocation of EWA resources has been significantly improved. However, research and understanding of the effects of the EWA needs to focus more on the ecosystem interactions. As a corollary to a shift in focus, the flow/export-centric emphasis in research and management needs to be reevaluated and approached in a more mechanistic manner. Other impacts of ecological processes on fish survival and life history processes need to be considered along with the impacts of flow and exports.

Specific issues from the workshop

The presentations from the 2005 EWA workshop updated research on salmon and presented a number of analyses on factors affecting delta smelt. The salmon presentations and many of the delta smelt presentations took a flow/export centric perspective: survival or population abundance was related to directly to EWA actions at the exclusion of other ecological factors. While this was not the case in all presentations, correlations of fish dynamics with flow/export was a dominant theme. Here I discuss some alternative approaches.

Delta Action 8 experiment

The first EWA review in 2001 identified the need to quantify the indirect mortality within the Delta and over the 5-year period EWA research accomplished this objective. Relative and absolute estimates of Sacramento salmon survival through the mainstem of the river and Delta passage routes have been measured and related to water exports from the Delta. These experiments were conducted to answer the management question (USFWS 2005):

> *Should the inflow/export ratio be reduced between November and January to protect juvenile salmon migrating through the Delta at that time?*

Accompanying this question the objective of the Delta Action 8 studies was:

> *To quantify the relationship between Central Valley Project (CVP) and State Water Project (SWP) exports and juvenile salmon survival through the Delta between November and January.*

To answer the above question, fish over a number of years were released into the mainstem at Ryde, and into the inner Delta at the top Georgiana Sough, and were recaptured at Chipps Island. The study addressed whether or not exports affect the ratio of survival through the inner-Delta passage route relative to survival through the mainstem of the Sacramento River (Figure 1). A linear regression suggested that the ratio of survivals was related to exports ($p < 0.1$). Increasing exports decreases the inner Delta/mainstem survival ratio (Figure 2).

This research suggests that total survival can be improved by decreasing water exports in the winter. However, is this a good use of EWA resources? If the goal of is to improve Sacrament fish juvenile passage, are there other research questions and other management actions that could be more efficient?

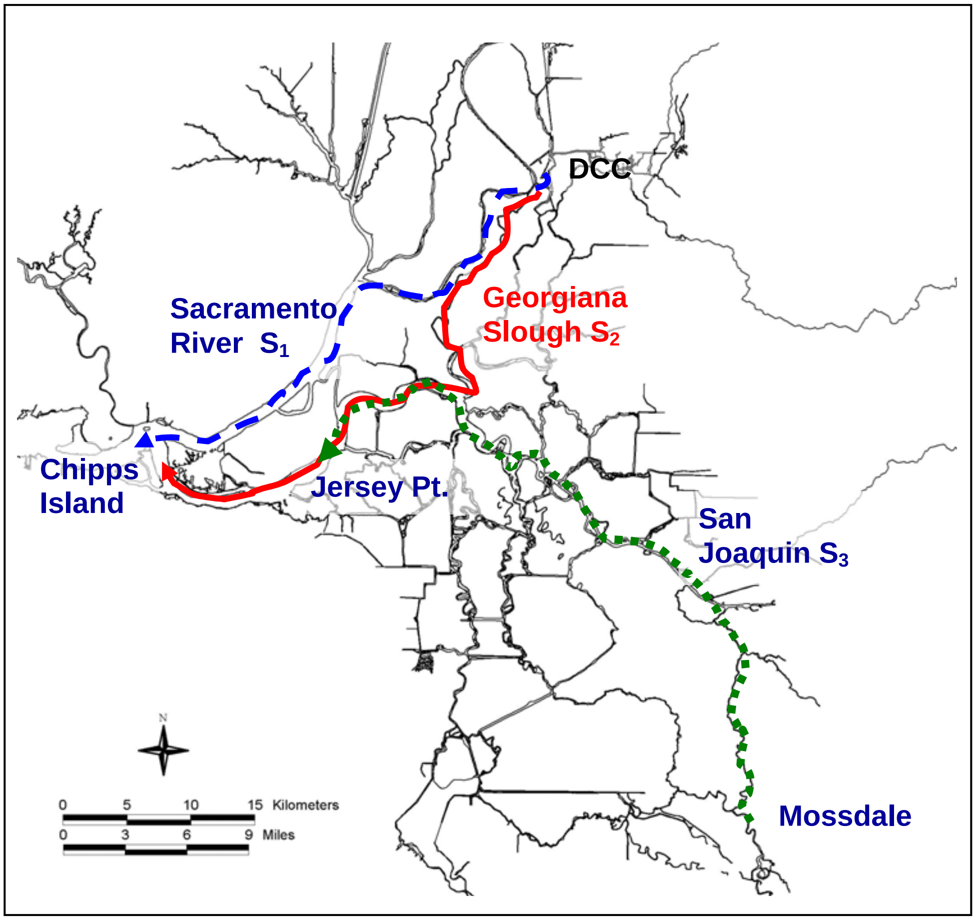

Figure 1. The Delta Action 8 experiment determines the ratio of survival of juvenile salmon passing pass through the main channel of the Sacramento River (S_1) relative to passing through the Delta via Georgiana Slough (S_2). The VAMP experiment determines the survival (S_3) between release sites near Mossdale and recapture at Jersey Point.

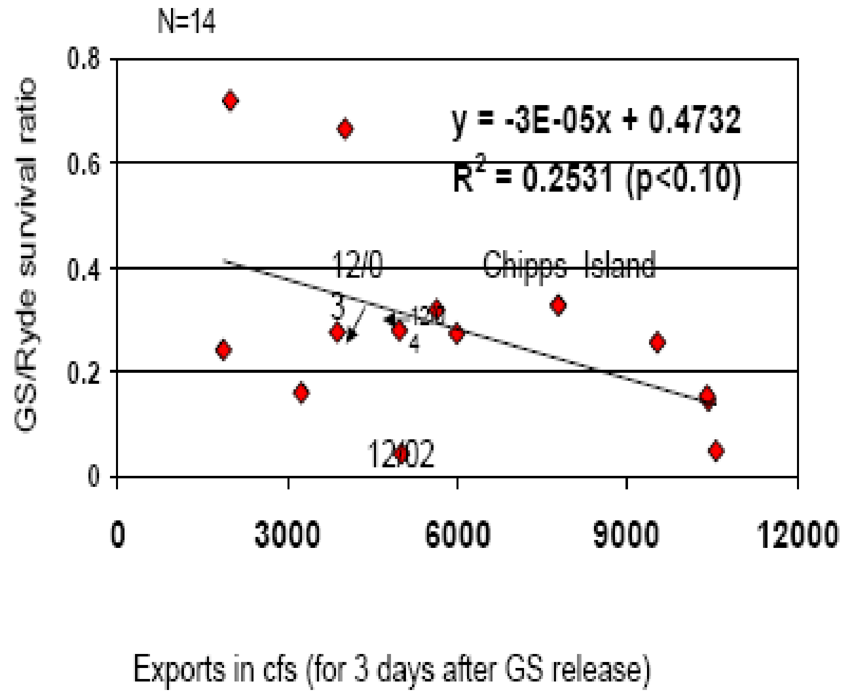

Figure 2. Relationship between GS/Ryde survival ratio (using Chipps Island survival indices) and combined exports 3 days after the Georgiana slough release) (Figure 3 from Brandes, 2005).

The detailed movements of salmon through the Delta have also been characterized, and we know the movement of fish at channel junctions. For instance into the DCC and Georgiana Slough, depends significantly on the tidal flow. However, fish survival studies have focused mainly on the effect of exports while little attention has been given to the dynamics of the fish movements at the junctions.

Exploring alternatives

As a first step in exploring whether export reductions are an efficient way to reduce smolt migration mortality, consider the effects of survival in a simple mechanistic model of fish passage. My purpose is to illustrate that to evaluate the relative effects of alternative actions, they need to be represented within a single model. Sometimes the information is insufficient to evaluate the efficacy of alternative actions; here a model can help guide thinking into research needs.

We begin by revising the Delta Action 8 experiment management questions to read:

> *Should smolt survival be increased by excluding fish from the inner delta or by reducing exports?*

Accompanying this question is the objective:

> *To quantify the effect of relative survival through altering fish routing.*

This revised question takes a more general and more ecological perspective, in which the routing of fish over the migration determines the total migration survival.

To compare the effect of exports to the effect of diversion into the Delta we begin with the model presented in the "*The use of the Environmental Water Account for the Protection of Anadromous Salmonids in the Sacramento/San Joaquin Delta in 2000-2001*" (Brandis pages 41-43). In this formulation, fish enter the estuary by one of two routes: they pass through the main river channel or are diverted into the inner Delta (Figure 1). The total migration survival, *S,* depends on the fraction of fish taking each route. This survival, relative to the maximum possible survival, $S_{max,}$ from above the Delta Cross Channel to Chipps Island is expressed

$$\frac{S}{S_{max}} = 1 - f + fR \qquad (1)$$

where *f* is the fraction of fish entering the Delta through the Delta Cross Channel and Georgiana Slough and *R* is the ratio of survival of fish passing through the Delta to the fish passing through the mainstem of the river. This equation assumes that the maximum survival occurs when fish pass through the river so $S_1 = S_{max}$. EWA scientists have developed several models that describe how *R* changes with water exports (Brandis et al. 2001). The simplest model is

$$R = S_2 / S_1 = a - bE \qquad (2)$$

where $a = 0.00003$, $b = 0.47$ (Figure 2). Equations (1) and (2) together characterize the relative survival in terms of exports, *E,* and the fraction of fish entering the inner Delta, *f* (Figure 3). The effect of exports on survival is more gradual than the effect of the fraction that enters the Delta. For example, reducing *f* by 0.15 gives the same survival improvement as decreasing *E* by 5500 cfs. Therefore, a greater benefit might be obtained by keeping fish from entering the Delta Cross Channel and Georgiana Slough than by reducing water exports.

Implicit in this model is the assumption that exports affect the fraction of fish that enter the Delta and are subsequently recovered at Chipps Island. Thus, *E* is indirectly a routing parameter equivalent to *f*. Studies on fish tagging indicate that the routing of fish at channel junction points depends strongly on the stage of the tide at the time of passage. Additionally, fish location across the river, the geometry of the junction and the mean river flow are also important. However, radio tagging experiments provide compelling evidence that fish move with the tides, especially in the inner Delta, and this is of paramount importance in determining their routing through the Delta.

This simple analysis suggests that a better understanding of the factors that affect fish routing can lead to significant improvements in fish passage survival. Similar analysis could be applied to salmon moving through the lower San Joaquin River. The principles are identical: survival depends on channel junction routing and the conditions and fish residence time in each channel.

The conclusion that *f* is potentially a more efficient factor to manipulate than *E* presents us with two additional questions: 1) what factors affect fish diversion at channel junctions and, 2) how can the factors be altered to control fish diversion? However, diverting fish is notoriously difficult and involves understanding the hydraulics of the environment and the response of the fish to the hydraulics. While such research requires a significant effort, considerable progress has already been made through the Delta radio tag studies and the development of tidally driven particle tracking models. Additionally, models that describe fish behavior to hydraulic fields (Goodwin et al. 2006) can be used to link the hydraulic and fish trajectory studies. Combining these tools, it is feasible to design and evaluate structures to direct fish into better migration routes through the Delta.

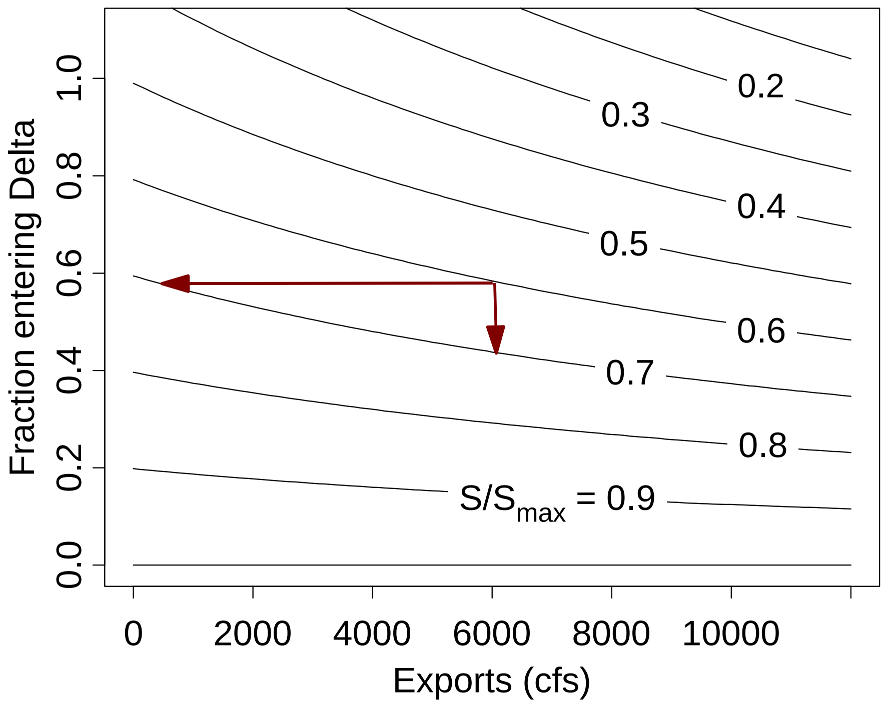

Figure 3. Effect of changes in water export and the fraction of fish entering Delta on the relative passage survival, S/S_{max}. Arrows illustrate that relative survival can be increased from 0.6 to 0.7 by reducing exports from 6000 to 500 cfs or by decreasing the fraction entering the Delta from 0.6 to 0.45.

VAMP experiment

The Vernalis Adaptive Management Plan presents us with a second example of the value of using mechanistic models to evaluate EWA actions. A major goal of the VAMP experiment is to quantify the effect of San Joaquin River flow on survival through the lower river. To establish this relationship, juvenile salmon were tagged and released in the vicinity of Mossdale and Jersey Point and were recaptured near Chipps Island (Figure 1). The ratio of the percent recaptured from each site is a measure of survival through the lower San Joaquin River. The relationship between flow and this survival measure has been characterized with a linear regression (Figure 4).

While a linear relationship is intuitive and is somewhat supported by the data, a deeper, more mechanistic, look at the issue is warranted. From theory (Anderson, Gurarie and Zabel 2005), smolt survival depends on migration distance and the total time of migration, with the significance of each factor depending on the probabilities of migrants encountering predators. If smolts move downstream in a continuous manner, they pass through a gauntlet of stationary predators; their survival depends on distance traveled, not on the travel time. However, if smolts move back and forth during their migration, as would be expected in tidally influenced reaches, then multiple encounters with individual predators can occur and survival depends on total exposure time as well as distance traveled. Which factor is most important, travel distance or travel time, depends on the amount of directed vs. random or oscillatory migration behavior. This model is known as the XT survival model. In addition to migration distance and time, environmental conditions, such as water clarity and temperature, can affect the predator activity and the chance of predator-prey encounters. A consequence of the XT model is that survival is independent of fish migration time at a high migration velocity and dependent on migration time at a low fish velocity.

To apply this model to the VAMP experiment, we assume that average fish migration velocity is proportional to flow, then travel time is inversely proportional to flow and from the XT model the survival relationship can be written

$$S = \exp\left(-a\sqrt{X^2 + b/F^2}\right) \tag{3}$$

where *a* and *b* are model coefficients, *X* is the migration distance and *F* is the flow at Vernalis. Fitting the model to the data indicates that migration is not gauntlet-like, and therefore migration time should be more important than migration distance in determining survival. In this situation, survival between Mossdale and Jersey Point simplifies to

$$S_3 = \exp\left(a + b/F\right) \tag{4}$$

where *a* and *b* are model coefficients obtained by regression (Figure 4).

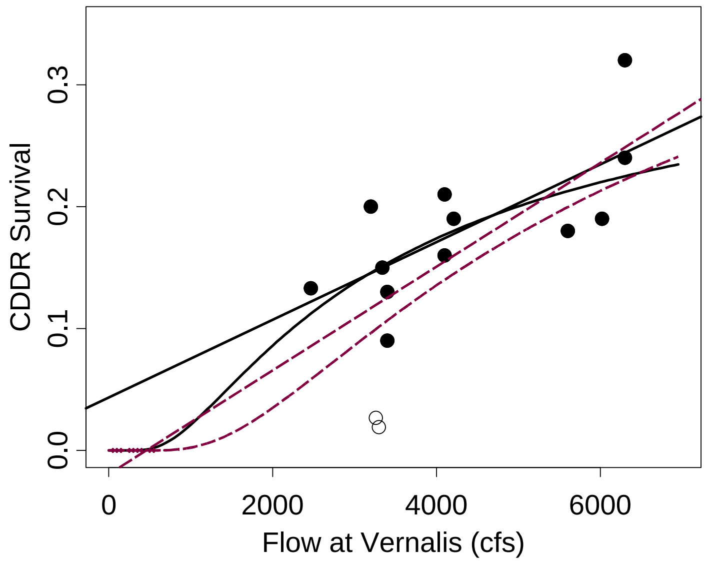

Figure 4. Combined Differential Recovery Rate (CDRR) from Durham Ferry and Mossdale to Jersey Point with HORB in place versus San Joaquin River flow at Vernalis in cfs, 1994, 1997, 2000-2004. Lines are equation (4) model and linear model fits with (- - - -) and without (——) the 2003 low survival data (open circles). Redrawn from Figure 7 in Brandes (2005).

Note that in Figure 4 neither the linear nor the equation (5) fits the data adequately when the 2003 low survival data is included (dashed lines in Figure 4). This suggests that factors other than flow, migration distance and travel time affect fish survival through the river. The XT-type models can readily include other significant factors such as temperature and water clarity, which can alter the interaction of smolts and predators.

Applying a mechanistically realistic model is more than of scientific interest only because the projections of the linear and XT models at low and high flows are significantly different. The linear model suggests a gradual decline in survival with decreasing flow, whereas an XT-type model predicts a greater decline in survival at low flows and diminishing benefit of flow as flow increases.

Developing a better understanding of the factors affecting survival of fish migrating through the San Joaquin River should be feasible with a reanalysis of the survival data including environmental covariates in a mechanistic model of the type illustrated above. Such a model may explain anomalous data, such as the results in 2003, and would provide a more realistic characterization of the effect of river flow on survival.

Delta smelt studies

The ecology and life history of delta smelt is considerably more complex than the migration ecology of Delta salmon. For salmon the ecology involves fish routing and survival over the various routes through the Delta. For delta smelt population dynamics must be considered which involve reproduction, growth, natural mortality, take at the pumps and their complex migratory behavior within the Delta. Furthermore, understanding delta smelt dynamics is now particularly critical because of the unprecedented low population levels of delta smelt and other resident pelagic species in the Delta.

It was evident from the workshop background material and presentations that the understanding of delta smelt ecology and their real-time management has advanced considerably in five years. The report of EWA actions in 2005 (Poage 2005) conveyed a real sense of drama as managers collected and evaluated an impressive array of information on the distribution, movement and spawning status of delta smelt. Especially commendable was the ability to quantitatively estimate the number of delta smelt saved by EWA actions. While the real-time management can be improved, and undoubtedly will, the current system is significant achievement.

Unresolved however is the significance of EWA actions on delta smelt population dynamics and the causes for the current low populations. These issues were not addressed by the agencies in the workshop, but were discussed by the stakeholders. Two hypotheses were proposed: 1) declines are cause by exports (Swanson 2005), and 2) declines are caused by food limitations (Miller, Ritton and Mongan 2006). Both studies were preliminary and in neither study were conclusions and findings sufficient to warrant management recommendations.

The Swanson study, which attributed population declines to exports, contained problems and possibly incorrect interpretations of the data. Population trends were characterized over time intervals in which major ecosystem changes may have occurred for reasons that cannot be attributable to water exports. Nonetheless, the study contained specific recommendations for export operations.

> *Using the regression equation for the relationship between winter exports and adult delta smelt abundance, this corresponds to average winter exports of approximately 4000-7000 cfs, similar to the range of exports measured during the 1995-1999 period (average: 5850 cfs). These results also suggest that recent winter export levels (2000-2005 average: 9150 cfs) are incompatible with recovery of delta smelt (Swanson 2005).*

Regressions of population trends against a single variable are not sufficient to make statements concerning population dynamics and recovery probabilities.

The Miller et al. (2006) study suggested that declines in *pseudodiaptomus*, a primary prey of delta smelt, could be the major factor in their decline. While this study and hypothesis have an ecological basis, it needs further development. It did not address the impact of fish loss through water exports nor was the analysis evaluated in the context of a life cycle model. Therefore this work is preliminary also.

It is noteworthy that the distribution of delta smelt across the Delta leads to divergent hypotheses on the significance of exports on the population. In recent years the highest numbers were observed Suisun Bay and about Chipps Island (Poage 2005). Bennett recently stated that delta smelt were never prevalent in the southeastern Delta (Bennett 2005b). However, the 2005 EWA actions to some degree were developed according computer model predictions of fish movement through the southern delta. An observer might wonder if the EWA real-time actions were targeting an area that was simply not occupied by delta smelt or if the exports decimated the population in the southern region. In either case the impacts of loss to the pumps on the northern delta populations and the total population within the Delta is unknown. Resolving this uncertainty should be a primary goal of CALFED research.

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