Towards a relational concept of uncertainty: Incorporating the human dimension

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Abstract

In this paper, we extend the conceptualization of uncertainties in natural resources management. Uncertainties come in different kinds, as it is apparent from the multiple classifications and typologies of uncertainties in the literature. Here, we re-contextualize uncertainty in a broader way - its role, meaning and relationship with knowing and acting persons - because it is from this relationship where problems and solutions emerge. We argue that uncertainties have a relational aspect that has to do with how decision makers relate, through their knowledge and actions, to the human-technology-environmental systems to be managed – an aspect that is not fully taken into account in the current literature. Our aim in this paper is to include the human dimension more fully in the conceptualization of uncertainties by (1) adding ambiguity as an important kind of uncertainty, (2) re-conceptualizing uncertainty as relational, and (3) indicating some implications of this re-conceptualized overview for strategies for dealing with uncertainty in water management.

1 Introduction

During the last decades uncertainty has become a dominant subject in the natural resources management literature (Pahl-Wostl, 2007; Borchers, 2005). This led to a re-evaluation of the way in which natural systems are managed and stimulated a search for different solutions than only technical ones. Eliminating uncertainties by engineering a system and controlling it is no longer considered as the only or best option (Gleick, 2003). The increased awareness for system complexity and uncertainties promoted the development and application of approaches, such as adaptive management, which claim that in order to deal with uncertainties it is necessary to create flexible solutions that are able to adapt to unknown and changing conditions (Lee, 1999; Pahl-Wostl, 2007).

Assessing and handling uncertainties is an increasingly important issue in natural resources management, in several ways (Campolongo et al. 2000). That predictions or measurements are to be interpreted as plausible ranges of values rather than exact points has long been acknowledged in the natural resources management field. An important and more worrying insight originated in the field of complex systems modeling, where it appeared that small variations in initial values or boundary conditions for a model could drastically influence model predictions (Haefner,1996). Due to complex dynamics, some systems are even considered to be unpredictable over large time-spans, e.g. the weather system (Cillier, 1998).

However, uncertainties are not only associated with complex natural systems, and are not only relevant in the context of modeling, although a large part of the uncertainty literature focuses on these aspects. Uncertainties are also associated with the behavior of people, organizations and social systems, as has long been recognized in the social sciences. Emery and Trist (1965), for example, describe organizational fields where several organizations compete for resources and deliberately create uncertainties for each other through the strategies they devise. They identity "turbulent fields", where stakes are high and changes are quick and hard to predict. In general, reactions of individual persons, future socio-economic developments or the outcomes of political struggles are very hard to predict with any accuracy.

While this work has learned us a lot about the *limits* of our knowledge, we think it is important to add the *multiplicity* of our knowledge to the uncertainty discussion. In natural resource management, there are often large differences regarding how to understand the nature of the problems, which often go together with profound differences in experiences, disciplinary background, expectations or values at the individual and collective level (Bradshaw and Borchers, 2000). The work of Patt (2007) relates to this issue insofar that he highlights the importance of differentiating model-based uncertainty from uncertainty resulting from expert disagreement (in global climate change assessment panels), which he calls conflict-based uncertainty. In the last case, uncertainty has perhaps less to do with incomplete knowledge but with multiple valid views of frames about the nature of the problem. This kind of uncertainty we will refer to as *ambiguity* or the simultaneous presence of multiple equally valid frames of knowledge (Dewulf et al., 2005).

We focus on a knowing subject who is somehow affected by this uncertainty, in understanding a problem and reacting to it; mediating the translation of uncertainty into an action choice (e.g. in making a model, in assessing a situation or in making a water management decision, Pahl-Wostl, 2002). But there is more to it than an individual subjective understanding. By including ambiguity, we recognize that the meaning that is given to a situation does not uniquely depend on a single individual, but it is shaped by the social context in which the subject is embedded, or the communities of practice in which he or she takes part (Wenger, 1998). Subjects are not isolated, but are part of a society, so any action choice is influencing and influenced by other subjects. Different subjects may hold different views about the same system, which not only influence the way in which problems are understood but the type of actions derived. As suggested by several authors (Pahl-Wostl, 2007; Duijn et al. 2003), being explicit about such diversity of views is important because it allows analyzing multiple views on the problem situation and discovering more innovative methods of actions than the ones that are usually considered within a single view on the problem.

In order to better incorporate the human experience and the multiplicity of knowledge into the conceptualization of uncertainty, we believe it is necessary to re-contextualize uncertainty in a broader way - its role, meaning and relationship with knowing and acting people. In this paper, we draw on work in the management and organizational sciences on dealing with uncertainty, where a distinction between uncertainty and ambiguity is made (Weick, 1995; Daft & Lengel, 1984), to extend the conceptualization of uncertainties in natural resources management. We argue that uncertainties have a relational aspect that has to do with how decision makers relate, through their knowledge and actions, to the human-technology-environmental systems to be managed – an aspect that is not fully taken into account in the current literature. Our aim in this paper is to include the human dimension more fully in the conceptualization of uncertainties by (1) adding ambiguity as an important kind of uncertainty, (2) re-conceptualizing uncertainty as relational, and (3) indicating some implications of this re-conceptualized overview for strategies for dealing with uncertainty in water management.

We will first outline the conceptual basis for a relational understanding of uncertainty, and its implications for water management. We will support these ideas by identifying important dimensions of uncertainty which can be combined into a 9-cell typology of uncertainties. Finally, we lay out the implications of our analysis for identifying relevant strategies for dealing with different kinds of uncertainties.

2 Uncertainty and the role and importance of problem framing

Developed in various domains and disciplines, uncertainty has been defined differently by different authors (see Walker et al. 2003 for a review). For example, Funtowicz and Ravetz (1990) describe uncertainty as a situation of inadequate information, of three kinds: inexactness, unreliability and border with ignorance. With a focus in modeling, for Zimmerman (2000) uncertainty is 'the situation in which a person does not dispose about information which quantitatively and qualitatively is appropriate to describe, prescribe or predict deterministically and numerically a system, its behavior or other characteristic'. Similarly, Walker et al. (2003), defines uncertainty as 'any departure from the unachievable ideal of complete determinism'. On the other hand, Klauer and Brown (2004) and Refsgaard et al. (2005) take a more subjective stance and consider uncertainty is 'the lack of confidence a person has about the specific outcome of an event or action.' Each of these definitions makes emphasis on different aspects of uncertainty, reflecting different views on the topic and implying different coping strategies. This is an important issue in adaptive management since different disciplines need to be brought together to find solution that are adequate from multiple perspectives.

Amid the discrepancies/variety in definitions, one thing upon which many authors agree is in the distinction between the ontological and epistemic nature of uncertainty. This distinction is important because it suggests different ways of addressing uncertainty (Walker et al 2003).Klauer and Brown (2004), Refgaards et al. (2005) and Walker et al (2003) refer to epistemic uncertainty, as the imperfection of knowledge about a system, and to variability uncertainty (ontological), as the inherent variability or unpredictability of the system. Similarly, van Asselt and Rotmans (2002) in their typology of sources of uncertainty, make the difference between variability uncertainty and limited knowledge. In this paper, we incorporate a third dimension in the nature of uncertainty, and refer to ambiguity as the simultaneous presence of multiple frames of reference about a certain phenomenon (Dewulf et al. 2005).

The concept of multiple frames tries to capture the difference between multiple but equally valid forms of knowledge, which results in ambiguity (Dewulf et al., 2005). Weick (1995) defined ambiguity not a as a lack of information, but as too many interpretation possibilities of a situation. For example, a situation of water shortage can be seen as a problem of ‘insufficient water supply’ for one actor, and one of ‘excessive water consumption’ for another one. Formulating a problem in a different way will elicit distinct preferences and point towards other solutions. In the first case technical solutions that help providing more water can be favored (e.g. building a dam). A decision maker in this situation will be concerned with knowing as best as possible, the amount of water available. In this context, uncertainties associated with this amount will be the most relevant. However, when the problem is framed as an excessive water consumption issue, other solutions can be favored, such as to change the way in which water is used and consumed (e.g. change land use). Here, other uncertainties become significant, such as those associated with how the society can react to a diversification of crops or activities. However addressing the uncertainties within either or both of the problem frames will still not resolve the uncertainty resulting from the simultaneous presence of the two different but equally valid views or frames about on the water situation.

Hence, the relevant dimension for ambiguity is not the one from complete knowledge to complete ignorance, but something ranging from unanimous clarity to total confusion caused by too many people voicing different but still valid interpretations. Considering ambiguity as a different *nature* of uncertainty (rather than just another *source* of uncertainty) can also help to develop more useful strategies to deal with it. Rather than 'correcting' different frames until they are more similar (epistemic strategy) or accepting these frame differences as an unchangeable fact (ontological strategy), strategies can be developed that aim at negotiating a mutually acceptable view or at finding a workable relation between the different views and actors.

Including the ambiguity that arises from the simultaneous presence of multiple knowledge frames requires us to propose a new, broader definition of uncertainty for natural resources management. We suggest the following "*uncertainty refers to the situation in which a decision maker does not have a unique and complete understanding of the system to be managed*".

3 Elements and conditions and for the occurrence of uncertainty

Uncertainty is associated with the knowledge a decision maker has about the system managed. It manifests when an actor becomes aware that some kind of intervention or facilitation is needed in a system, while the actor does not have a unique and complete understanding of the system. For this to happen there must be an object of perception/knowledge (e.g. the river system) and one or more knowing actors (e.g., decision maker) for whom that knowledge is relevant.

At some point in time, there is a change in how a knowledge situation is perceived. This change can be triggered by one or more causes, internal or external to the actors, and it should be persistent through time so it can be detected. The actors have to make sense of the new situation and to determine how to act. For example, a farmer can become aware of how their practices modify the natural landscape by the excessive consumption of water. She may want to change their practices based on how much water is considered to be safe to spend. However, there could be uncertainties about which is an appropriate quota of water. So, the farmer must make a decision considering she doesn't exactly know how much water she disposes.

Treating uncertainty as a relation requires three elements:

1. An object of knowledge;
2. Knowing actors;
3. A knowledge relationship established among the actor and the object

An actor establishes a relationship with the object that is unique in its meaning. Besides, an actor is not isolated, but embedded in a context of other actors to whom she interacts. These other actors relate with the object in their own way, giving different meaning to the situation and influencing each other. Making this explicit is important because alternative relationships can change the meaning of the problem and its solution.

3.1 Types of uncertain knowledge relationships

Based on the distinction of uncertainty done by its nature, we identified three types of knowledge relationships: multiple knowledge frames, incomplete knowledge and unpredictability. Each of these relations differs in the nature of the involved uncertainty (ontological, epistemic, ambiguity) and thus, the kind of knowledge it represents.

3.1.1 Unpredictability

The systems to be managed are complex systems, whose behavior is variable in space and time. These systems are constantly learning and adapting to new conditions. They express a non-linear and sometime chaotic behavior, and are very sensitive to initial or boundary conditions. These characteristics make them impossible to be predicted. With this kind of uncertainty, we accept the unpredictability of the system as something that will not change in the foreseeable future.

3.1.2 Incomplete knowledge

This type of relationship refers to situations where we don't know enough about the system, or where our knowledge about it, is incomplete. This can be due to a lack of information or data, to the unreliability of the data that is available, to lack of theoretical understanding, or to ignorance. Uncertainty that comes from incomplete knowledge can, in some situations, be reduced when having the necessary time and means.

3.1.3 Multiple knowledge frames (ambiguity)

Frames are what mediate the interpretation of reality, and as such they serve to contextualize a situation. Framing is the process through which the meaning of a situation is constructed (Gray, 2003). Here, we follow an interactional approach to framing (Dewulf et al., 2004; Putnam and Holmer, 1991) which considers that frames are the results of ongoing interactions among different actors. Thus, by framing an issue a decision maker defines a problem, highlighting certain aspects of it and ignoring others. Interwoven the social interactions, there are factors, such as normative assumptions, budget and access to information, cultural values and beliefs, that also influence the framing process.

This relationship refers to different, and sometimes conflicting, views about how to understand the system. Ways of understanding the system can differ in where to put the boundaries of the system or what to put in the focus of attention. Certain information can be associated with entirely different meanings (e.g. about what the most urgent problems are) or there can be contradictory evidence about what the implications are.

3.2 Objects of knowledge

The objects of knowledge (*sensu* van Asselt & Rotmans, 2002) considered are: the natural, the technical and the social system. Although we assume that these systems are closely interlinked in a complex natural-technical-social system, it is useful to distinguish to which part of the system an uncertainty refers.

a. Natural system. This includes the natural system with its aspects of climate impacts, water quantity, water quality, and ecosystem.

b. Technical system. This includes the technical elements that are deployed to intervene in the natural system, like infrastructure, technologies.

c. Social system. This includes the social system, with its economical, legal, political, organizational and stakeholder aspects.

	Unpredictability (unpredictable system behavior)	**Incomplete knowledge** - lack of information - unreliable information - lack of theoretical understanding - ignorance	**Multiple knowledge frames** - different and/or conflicting ways of understanding the system - different values and beliefs
Natural system - climate impacts - water quantity - water quality - ecosystem	Unpredictable behavior of the natural system E.g. what will be the highest water level next year?	Incomplete knowledge about the natural system E.g. unreliable measurements of water levels	Multiple knowledge frames about the natural system E.g. is the main problem in this basin the water quantity or ecosystem status?
Technical system - infrastructure - technologies - innovations	Unpredictable behavior of the technical system. E.g. what will be the side effects of technology X?	Incomplete knowledge about the technical system E.g. to what water level will this dike resist?	Multiple knowledge frames about the technical system E.g. should we raise dikes or create flood plains?
Social system -organizational context - stakeholders -economical aspects - politic aspects - legal aspects	Unpredictable behavior of the social system E.g. how strong will the reaction of stakeholders be at the next flood?	Incomplete knowledge about the social system E.g. what are the economical impacts of a flood for the different stakeholders?	Multiple knowledge frames about the social system E.g. do we need to impose insurance against floods or adapt the legal regulations about spatial planning?

Table 1. Uncertainty matrix

If we combine both dimensions, the three uncertainty relationships can be applied to the three subsystems of the water management regime. Each combination leads to specific uncertainty questions (Table 1). These columns are not independent, but serve to characterize our understanding of the system to be managed.

4 Strategies to deal with uncertainty

The types of uncertainty define a knowledge relation between a knower and a phenomenon. This knowledge relation implies a specific understanding of the nature of the situation, and this understanding will suggest certain strategies to deal with the uncertainty and avoid others. Each knowledge relation suggests a range of relevant strategies to deal with the uncertainty, but this range differs as we move between the columns in the above Table. In this section we concretize this idea, by identifying a range of relevant strategies for each type of uncertain knowledge relationship (unpredictability, incomplete knowledge and multiple frames).

4.1 Strategies for dealing with Unpredictability

The uncertain knowledge relationship we termed *unpredictability* implies the acceptance that we are not able to make useful predictions about a phenomenon. It also implies the acceptance that doing more research will not change this situation in the near future.

What can we do when a phenomenon that is of importance to us behaves in unpredictable ways? Ackof (1983) argued that *control* is the first strategy that comes to mind. If we cannot predict a phenomenon, we can still try to influence it by intervening in the system to create favourable conditions. If we cannot predict the variations in the flow rate of a river, we can still try to build a dam to artificially control the flow rate. Although control measures have proven to be useful in the context of natural resources management, many scholars argue that we have reached the limits of what can be achieved. The bigger the control measures, the larger the sunk costs and the less flexible the system becomes to deal with other new challenges.

If control is not an option, we somehow have to learn to live with the unpredictability. Being able to respond quickly and effectively to whatever we encounter is a possible strategy, which eliminates the need for either prediction or control. To be able to respond quickly and effectively on the long term requires continuous learning and *adaptation*.

A range of strategies can be identified in situations where a phenomenon that affects an activity we consider important cannot be predicted or controlled (some of which overlap in meaning):

- Extending the range of situations to which we can respond effectively called contingency planning (Ackof, 1983).
- Take mitigation measures to reduce the negative effects of undesirable scenarios
- Take insurance
- Search for robust strategies, which produce desirable results under the largest possible range of variation in the phenomenon of interest.
- Opportunity catching: plan less and organize quickly when a positive scenario unfolds.
- The precautionary principle – if we cannot be sure that the outcome of our intervention will not cause severe harm, we do not intervene
- Install short cycles of monitoring and adjustment
- Diversification: keep multiple options open simultaneously.
- Stop considering the affected activity as important
- Fatalism: wait and see and accept that things can go wrong.

All these strategies could be subsumed under *adaptation*, in the sense that the unpredictability of the system is accepted and no prediction is attempted.

4.2 Strategies for dealing with Incomplete Knowledge

The Incomplete Knowledge relationship implies that, in principle, uncertainty could be reduced or even eliminated by carrying on more research, or collecting more or better data, in order to improve the description and understanding of the objects of knowledge.

To this end, science and the scientific method, through an incremental process of theory construction can gradually work towards increasing understanding and reducing uncertainties about a problem. The implicit idea behind this strategy is that objects of study are part of a reality for which there is an explanation (or a theory) that properly describes it. Thus, science seeks to come progressively closer to the truth by finding the single, best explanation possible: one that becomes gradually freer of uncertainties. (Mathematical) models can be used to derive testable hypotheses from theoretical assumptions that allow confirmation or refutation of hypotheses. Such procedures are a fundamental part of the scientific method that is assumed to guarantee the objectivity and general validity of the insights thus derived. Statistical sciences and pro

In this context, strategies that allow evaluating and quantifying the effects of uncertainty in models, such as sensitivity, uncertainty and scenario analyses, become important. Sensitivity analysis is a general approach to understand model behaviour, by studying the relationship between information flowing in and out of the model (Haefner, 1996; Beck, 2002; Saltelli 2000). The analysis aims at measuring the sensitivity of an output to variations in input factors, like parameters or input data. Uncertainty analysis constitutes another commonly used approach of uncertainty evaluation. It measures the uncertainty of models' results. This class of analysis is concerned with estimating the overall uncertainty of model output given the uncertainty associated with parameters or input data (Saltelli 2000). For example, Monte Carlo is a widely used method of uncertainty analysis that is based on a sampling of the entire input factor space (e.g., parameters, input data) and determines how uncertainty propagates through the model and affects model output. Applications of uncertainty and sensitivity analysis are not only restricted to investigate parameter and input data uncertainty, recent developments have expanded to investigate how uncertainty due to lack of complete understanding in the scientific concepts that are embedded into the model affects a model's internal structure and its emergent behaviour (Brugnach 2005). Scenario analysis is another approach to understand the effects of uncertainty. It aims at simulating different possible scenarios, each of which embeds different assumptions about the future.

Relevant strategies can be summarized as follow:

- range estimation (confidence intervals)
- uncertainty propagation in models
- more data gathering and research to complete lacking knowledge
- scientific method to improve factual knowledge base
- use expert opinions

All these strategies could be subsumed under *research*, or attempts to fill in knowledge gaps.

4.3 Strategies for dealing with Multiple Knowledge Frames

Multiple or conflicting views about how to understand the system often represent different kinds of knowledge that are difficult to reconcile or integrate. The incompatibility in frames may result from different scientific backgrounds, from differences between context-specific experiential knowledge and general expert knowledge, from different societal positions of ideological backgrounds, and so forth.

In relational terms, actor A has a certain knowledge relation to phenomenon X, and actor B has a different knowledge relation to the same phenomenon X. In these kind of situations, relevant strategies address the relation between A and B and have something to do with dealing with differences.

We draw on a Table (Table 2) from Bouwen, Dewulf & Craps (2006) to give an overview of relevant strategies to deal with multiple knowledge frames.

	Action Principle	**Accept. of Interde-pendence**	**Process Charac-teristics**	**Possible Outcomes**	**Context Contingen-cies**
Persuasive Communication Approach	Persuasion	Moderate	Exposure to persuasion	Adoption or imitation	Unequal involvement or competence
Dialogical Learning Approach	Mutual Interactive Learning	High	Joint discovery and exchange	Mutual understanding and synergy	Shared involvement
Negotiation Approach	Tit for that, deal making	High/ moderate	Negotiation tactical phases	Fair deal, settlement	Calculative involvement
Oppositional Modes of Action	cold or hot conflict	Low or negation	Keeping distance or escalation	Freeze or dominance	Mutual negation or fight

Table 2. Strategies to deal with multiple frames

The first strategy can be called the persuasive communication approach. This consists of trying to convince others of your own frame of reference, not by imposing it but by presenting it as attractive and worthwhile. This strategy is successful if others can be convinced to adopt your own frame of reference.

The second strategy is the dialogical learning approach, where the aim is to understand each other's frames better through open dialogue and encourage learning on all sides. The literature on participation, organizational learning and consensual group decision making documents extensively this approach (Argyris and Schön, 1978; Wenger, 1998). The emphasis is on the interactive nature and reciprocal quality of the communication. Actors engage with each other as equally valuable partners and inclusion of all actors is the overall goal.

The negotiation approach aims at reaching a mutually beneficial and integrative agreement which makes sense from multiple perspectives or frames. Theories of conflict in organizations deal extensively with these negotiation strategies. Actors engage in a mutual calculative information sharing and positioning strategy. They develop alternative packages for giving and taking to come to a balanced sharing of positives and negatives. The negotiation can have a dominantly ‘integrating’ quality when both actors develop in common some synergetic win-win outcomes. The negotiation can rather be ‘distributive’ when the actors take a win-loose position and they distribute equally profits and gains in an antagonistic way.

The fourth strategy is the oppositional mode. When parties have a history of rivalry for resources or they don’t have any history of collaboration, taking or holding distance is likely. In conflict theory the distinction is made between cold and hot conflict. Cold conflict means that there is no recognition of mutual interdependence and distancing from each other is a dominant mode of operating. Hot conflict refers to heated opposition as a result of an adversarial experience of the mutual interdependency. Parties try by force a strategy to change the power difference in the relationship. When it comes to some form of collaboration, parties will move their strategy in the direction of a negotiation approach.

4.4 Reconsidering the uncertainty relation as a strategy

On a higher level of abstraction, a strategy can also consist of changing the nature of the uncertain knowledge relation itself, and thus approaching the situation with qualitatively different strategies.

- From Incomplete Knowledge to Unpredictability: instead of trying to research more and more, and trying to make more and more models, let's accept that we will not know
- From Incomplete Knowledge to Multiple Knowledge Frames: instead of going on to search for the final right answer, let's accept that we look at the situation from very different perspectives
- From Unpredictability to Multiple Knowledge Frames: rather than accepting that we will never know the final answer, let's accept that we look at the situation from multiple perspectives which each give a partial answer
- From Unpredictability to Incomplete knowledge: rather than accepting that we will never know the final answer, let's try and make a new model based on the latest insights
- From Multiple Knowledge Frames to Incomplete Knowledge: rather than keep on focusing on our different frames, let's see if new insights can alter the nature of our discussion
- From Multiple Knowledge Frames to Unpredictability: rather than keep on focusing on our different frames, let's stop discussing and accept that we cannot say anything about it.

5 Conclusions

We propose to focus on the relational properties of uncertainty. In so doing, human actors, with their view and expectations, become part of the problem. Hence, the notion of uncertainty shifts from being an objective property of a system, to include in its definition the human experience. We consider uncertainty has no meaning in itself but through the relationship a decision maker establishes with the environment and other actors to make sense of a situation. Under this view, it is not possible for an actor to have a complete, objective and unique understanding of a system based on factual knowledge. The understanding is inseparable from the social context in which the actor is embedded, giving sense and meaning to the representation of the world (Pahl-Wostl, 2007).

We have identified three kinds of knowledge relationships: multiple knowledge frames (ambiguity), unpredictability and lack of knowledge, which are associated with the natural, technical or social systems. While unpredictability and lack of knowledge has been the focus of most of the discussion on uncertainty literature, here we incorporate multiple knowledge frames as a third dimension. This relationship, that can also be called ambiguity, and results from the presence of multiple ways of understanding or interpreting the system, which can originate from differences in professional backgrounds, scientific disciplines, value systems, societal positions and so forth. By framing an issue, it is determined the aspects of the problem that are important, the kind of knowledge that is considered, the assumptions actors hold, the views that prevail, all of which are crucial elements to determine intervention strategies. Further work will require investigating how to better capture the framing of uncertainties in environmental problems.

From a strategic point of view, focusing on the properties that define the uncertainty relation opens new possibilities of intervention. Dealing with uncertainty is not constraint to improve the factual knowledge base but also to change the way in which we relate with the natural systems. Thus, handling uncertainties shifts from elimination towards exploring other options by reconsidering our relation to the water management situation and the other involved actors. By reframing a problem, different relations can emerge. This can be achieved through reflections, dialogues and negotiation. In other words, to cope with uncertainty we do not necessarily need to do more research, but learn how to change.

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