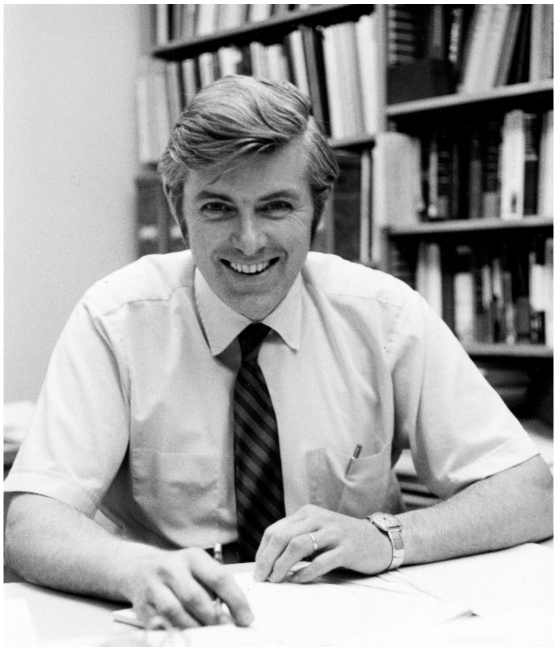

# NORMAN H. BROOKS
**(b. 1928)**

**INTERVIEWED BY**
**GEORGE PORTER**

**April 16, June 11 and 18, 2018**

**ARCHIVES**
**CALIFORNIA INSTITUTE OF TECHNOLOGY**
**Pasadena, California**

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## Subject area

Environmental and Civil Engineering

## Abstract

An interview in three sessions, April and June 2018, with Norman H. Brooks, James Irvine Professor of Environmental and Civil Engineering, emeritus.
He recalls his education at Harvard (AB 1949, mathematics; MS 1950, civil engineering); courtship of his wife, Frederika; their work in Boston settlement house; decision to come to Caltech for graduate work; teaching assistantship; attention to civil engineering curriculum.
Summer job for L.A. County Sanitation Districts leads to further studies in hydrology and sedimentation with adviser Vito Vanoni. Comments on founding of Keck Laboratory of Hydraulics and Water Resources, with Jack McKee and Pol Duwez; designs recirculating flume. Establishes Environmental Engineering Science [EES] option. Participation of James Morgan, Fred Raichlen, Robert Koh, Wheeler North, JohApriln Seinfeld. Founding of Environmental Quality Laboratory [EQL] under Caltech president Harold Brown, which he directed from

1974 to 1993. Participation of Seinfeld, Roger Noll, John List, James Quirk, James Krier, John Ferejohn, Glen Cass.
Throughout, he discusses the importance of firsthand observation of hydraulic issues, including sediment and pollutant dispersal and ocean outfalls; of taking a scientific approach to civil engineering; of understanding of ocean currents in using ocean as a resource for waste disposal. Recalls his numerous consulting jobs on ocean outfalls: Athens, Greece; Boston, Massachusetts; Sydney, Australia; Zurich, Switzerland; Taipei, Taiwan; Bangkok, Thailand; San Onofre nuclear plant.

## Administrative information

### Access

The interview is unrestricted.

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**Norman H. Brooks, March 1966**

**CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES**

**ORAL HISTORY PROJECT**

# INTERVIEW WITH NORMAN H. BROOKS

**BY GEORGE PORTER**

**PASADENA, CALIFORNIA**

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**NORMAN H. BROOKS**

**SESSION 1**

**April 16, 2018**

PORTER: Tell me about your childhood.

BROOKS: I was the sixth of seven children. I was born in 1928 and grew up during the Depression. My parents were interested in social welfare. My father was a meteorologist, and he was the founder and president of the American Meteorological Society. In my early years, he was a professor at Clark University, in Worcester, Massachusetts. In 1932, he became a professor at Harvard and also the director of Harvard's Blue Hill Meteorological Observatory, in Milton, Massachusetts, so I was four years old when our family moved to Milton. I lived there until I graduated from high school, at age sixteen.

PORTER: Where did you go to primary school? What teachers had an influence on you?

BROOKS: I went to public schools in Milton. In addition to my schooling, my whole family was very active in my education. My father was a great teacher, always pointing things out to me. He was a great explainer, and my mother too. I was very fond of nature. My mother had a biology degree from Radcliffe. She helped my father in writing and editing reports. My sister Sylvia taught me to read and write, and my sister Edith taught me arithmetic. I was instilled with a spirit of inquisitiveness. At Milton High School, I liked the algebra teacher a lot—she would single me out for the most difficult problems. My older brother started Harvard when I was five years old. He became a meteorologist, like my father.

PORTER: So you were in high school during World War II.

BROOKS: Yes, the attack on Pearl Harbor happened when I was in the ninth grade. VE day was in May of the year I graduated from high school. I had accelerated elementary school; I did grades four, five, and six in two years—I liked math the most. I was asthmatic as a child, so I didn't do sports, except for rowing at Harvard. When I started at Harvard, at seventeen, my father told me I had to have a career. He didn't push my sisters in this way. I decided to major in math—if you're good at math, you're able to do lots of things. When I was at Harvard, I had one-on-one tutorials with my math professor, Lynn Loomis, for three years. This helped me prepare for writing my Bachelor's thesis, as part of the honors program. My thesis was on abstract math, relating to proof of existence or nonexistence of solutions. I worked on it up to within a week of getting married. A main value of majoring in math was learning to think precisely and clearly—I learned the value of clear and logical thinking.

I enjoyed my childhood. We lived next to the Blue Hills Reservation. Do you know Blue Hills Reservation?

PORTER: I don't.

BROOKS: It's a large conservation and nature recreation area just south of Boston. I would walk there, observe different things. When it was raining, there were small creeks running—I would enjoy rearranging the rocks to make a dam. I didn't live on a street where there were other kids on the block, so I did a lot of things with my closest siblings, a just-older sister and just-younger sister, as childhood playmates. We did creative things—in the wintertime, we built igloos!

PORTER: So you explored math at Harvard, and I understand that you met your future wife around then?

BROOKS: My wife, Frederika, was a friend of my next older sister, Edith. Edith was a sophomore at Swarthmore when Freddie was admitted to Swarthmore as a freshman. As it happened, Edith was designated as Freddie's "big sister," and they've been good friends ever since. So that's how they met: Edith was chosen as Freddie's big sister because Freddie lived in East Boston, and Edith also lived in the Boston area. Freddie's father and mother at that time had a group of settlement houses in East Boston.

Settlement houses are community organizations for recreational activities for children and adults alike, and they help new immigrants to find their way amongst the complexities of American society. So Freddie was coming from a family with a lot of social concerns, public service—they were social-welfare organizers. I met Freddie when Edith brought her home for a visit when she was a freshman at Swarthmore. I was fourteen then. [Laughter]

PORTER: An older woman.

BROOKS: An older woman, that's right. We didn't really have an honest-to-goodness courtship until I was about eighteen, and even then it seemed like a far-off opportunity. But as I met other women, and as we got to the end of my college years, I decided after a lot of meditation that this young lady, this young woman, was somebody I wanted to spend the rest of my life with, and I didn't want her to get away just because I was finishing college. She was already working in her father's organization, managing a program in one of the settlement houses in East Boston.

PORTER: And her major at Swarthmore had been . . .?

BROOKS: English and Latin. She transferred for a while, to be a Latin teacher in private school, but she ended up working in the settlement house, where she also lived. So anyway, even though I was several years younger, we were headed to marriage. I proposed to her in the summer of my senior year at Harvard, at our family's summer place on the shores of Silver Lake, in New Hampshire. Our family acquired that house in 1932, when I was four years old, and I spent all my summers there until I went to college and then some, too. Freddie used to come to Silver Lake sometimes to visit Edith and our family, so she was well-known to my father and mother and my siblings, and she began to feel like a member of the family before she was. [Laughter]

We got married in December of '48, just as I was finishing up my undergraduate degree at Harvard. I graduated in January of '49, about six months early. The war was still going on when I started at Harvard, and they were offering entering freshmen students the opportunity to start in the summer of ’45 on an accelerated schedule, so I started that summer and was able to graduate a full semester earlier than I would have otherwise. That’s why we got married in December of ’48—because that was a good transition point for me, and Freddie was keen for us to move ahead with our lives. Once we married, I moved out of the Harvard dormitory and into the settlement house where Freddie lived. I became involved in the settlement house, and that was fine, because I had a social awareness and a willingness to volunteer.

PORTER: How do you go from graduating in January, and moving into the settlement house with your new wife, to going to Pasadena, of all places?

**BROOKS**: That was a couple of years later, and there’s quite a few things to explain in between. Shall we continue with that? Let’s continue with that, because when Freddie married me, she really had a lot of confidence in me, because I had not yet defined a career for myself. She didn’t know exactly what I was going to do next. [Laughter] And I didn’t know either, because, before graduating in January, I hadn’t figured out what I was going to do next. I did figure it out, because I became a graduate student at Harvard in physics starting right away, in February, in the second semester, even though I had no intention of continuing in physics. It was more a sort of buffer between graduating as an undergraduate in mid-year and not having figured out what else I was going to do.

As I mentioned, once we were engaged, Freddie wanted to get married sooner rather than later. So we got married. Marriage became a wonderful change, because Freddie was part of the decision-making. I couldn’t just say, “Well, I’m going to do this,” or “I’m going to do that.” Before we got married, I had already put in some applications to become a civil engineer—I’d gotten as far as deciding I wanted to be a civil engineer. I like management, being in charge of things. I took a quick look at things like being a school superintendent or a city manager, because I like managing things, but I quickly found out that that was not what I wanted to do.

The city manager at Cambridge would sometimes offer to take Harvard students out with him for a couple of weeks to see what being a city manager was like, and I followed up on that. I didn’t care so much for all the administrative stuff he had to deal with. But he sent me to the head of the Water Department, who gave me a complete tour of all the public works, waterworks, in Boston—the water supply—and how they pumped the water with huge pumps. I thought, "This is more like what I want to do." I hadn't really focused on public works, but this was how people got their water, and I thought I'd like to be associated with water. I was interested in rainfall; I'd learned how to measure the rainfall with my meteorologist father. I'd often hang around with him at the Blue Hill Observatory so I got to know about wind velocity and anemometers and other kinds of stuff.

PORTER: And many years later, you're going to come back to Boston public works and water and sewage and so on.

**BROOKS**: That's right.

PORTER: And we'll get to that later.

BROOKS: But anyway, that was a trigger—being out in the field with a public-works person. Seeing the various pumping stations and reservoirs and how they had to manage the water distribution, and so on, woke me up to knowing that I didn't want a desk job. I wanted something that had to do with the outdoors, and something that had to do with making things better for people.

The reason I got interested in leadership is because I had several leadership experiences at Harvard. Maybe I should mention those before I go ahead.

PORTER: Sure!

BROOKS: There's an organization called the Phillips Brooks House Association. It's an endowed undergraduate program for Harvard students. It started about 1904 and it was for encouraging students to be volunteers in the community. One of the programs provided volunteers to run recreational programs in settlement houses. This was years before I thought about being married to Freddie. My college roommate and I took over as co-chairmen of the social-service committee that was sending Harvard students to help settlement houses run their recreational programs—mostly sports but sometimes tutoring, and sometimes other things, whether it was going to the theater or whatever. Boston had quite a network of settlement houses, maybe about thirty of them, in the underprivileged neighborhoods. So between my roommate and me, we built up this social-service committee and sent two hundred Harvard students to volunteer in the Greater Boston suburbs.

PORTER: That's a substantial portion of the undergrad population.

**BROOKS**: Oh, no, the undergrad population was around five thousand. Also, I should mention that at Harvard, there was a flood of veterans, so that was—

PORTER: The beginning of the GI Bill?

**BROOKS**: The beginning of the GI Bill, that's right. Anyway, our volunteers weren't a huge percentage of the freshman class, but two hundred was a sizable number. Anyway, the Phillips Brooks House organization, the student organization, had about five hundred members. Not all of them were doing social work; there were different practicums. My roommate, Jay, and I became the co-presidents of this operation, because of these five hundred, we had about two hundred already under our supervision. I enjoyed doing that, and I found that I liked being in charge, because you have better control over making things happen. Anyway, that's also how I got plugged in to the settlement-house movement. In fact, we were actually sending volunteers for the programs at the settlement house that my future wife ran. [Laughter] So it wasn't like coming out of nowhere when I moved over to the settlement house to live there with my wife.

Getting back to your question of how we chose Caltech: Well, two things—no, three things. I had already put in some graduate-school applications to study civil engineering before Freddie and I got married. You get the acceptances back in the spring, so just a few months after I got married, I got an acceptance from Caltech. I had applied for a scholarship at Caltech, but I was awarded a teaching assistantship *and* a scholarship. I thought I'd probably like being a teaching assistant. I'd had some teaching experience, going back to when I was in the twelfth grade in my high school. The teacher who taught a class in trigonometry and solid geometry—an advanced, senior-level math course—couldn't always come to class. So can you guess what he did?

PORTER: Deputized you?

BROOKS: Yes. He said, "Norman, I would like you to take the class," which I did—not too often, but maybe three or four or five times during the year. I liked that, because it was a class of maybe twenty to twenty-five students. It was novel for them to have one of their fellow students give the lecture. And so what do you think they nicknamed me?

PORTER: Professor.

BROOKS: [Laughter] So I kind of enjoyed it—you know, explaining things to students and seeing the light bulb go on; I liked that about being a teaching assistant. That was reason number one to go to Caltech. The second reason had to do with my wife. The other place where I was accepted was the University of Iowa. They had an outstanding hydraulics program, which is my field of interest within civil engineering. But Freddie said, "Don't go to Iowa! I want to go to California." She'd been traveling the year before to some of the Western states, and she liked California. Iowa just didn't appeal to her.

The third reason is that one of my professors at Harvard said, "Well, you know, Caltech is really a fine, excellent institution in all of its fields, while the University of Iowa has a very good program just in hydraulic engineering but doesn't excel the same way Caltech does in other fields, so you'd be shut off from the opportunities of a broader graduate experience." And of course he was right. I discovered later that fluid mechanics is not the province just of civil engineering; it also involves mechanical engineers, aeronautical engineers, chemical engineers, and when I got to Caltech I found I was taking courses in different fields, getting different exposure to different students. So it was a good thing. My wife made a good call, and I agreed—based on logical grounds and other grounds as well. But even if I hadn't agreed, I still would have come to Caltech, because we'd just been married a short time.

PORTER: What year is it that you come to Caltech?

BROOKS: 1950. I was at Harvard getting a Master's degree in civil engineering in 1949-'50. Getting a Master's degree at Harvard was a good thing to do, because it made it more credible that I wanted to be a civil engineer and probably helped in getting me a good admission to Caltech. I'm told that when they were considering admitting me, Romeo Martel [professor of structural engineering, emeritus; d. 1965] said, "He has hardly any civil-engineering background. He was a mathematician." George Housner [Braun Professor of Engineering, emeritus; d. 2008] said, "Don't worry, he's smart enough with a background in mathematics."

Anyway, I was admitted to Caltech with a teaching assistantship. In the admissions letter, the graduate dean, Dean [William N.] Lacey, invited me to come and see him when I got to Caltech. So when I arrived, I went to see him. He said, "We have a new assistantship for you, to teach third-year calculus as a teaching assistant." You probably know what third-year calculus means—it's beyond first-year calculus. The second-year calculus would be partial variables, and the third year is where you learn all about partial differential equations, Laplace transforms, Fourier analysis, infinite series, and all of that. Here I am, twenty-two years old, walking into a class full of veterans. I said, "I don't really think I'm quite up to it, because I didn't study all of these subjects." I had been doing a lot of different things at Harvard: I was paying attention to getting a broader education, taking social-relations classes, music, and so on—I wasn't just a nerd at Harvard. I think my family pushed me. My sister said, "Oh, you should take this course in music," and somebody else said, "Well,"—because a lot of them went to Harvard—"do this." So, to get back to the story here, I told Dean Lacey, "I don't think I'm up to teaching that, because I'm not familiar with all the subjects." I explained that I had studied *some* of them. I was more into applied math, using differential equations. So they gave me a different class to teach—Materials and Dynamics, under George

Housner's supervision. He was my mentor. In those days, engineering was much more popular, and the other fields, like biology and chemistry, weren't flourishing so much.

PORTER: Had George Housner and Don [Donald E.] Hudson [professor of mechanical engineering, emeritus; d. 1999] written their first textbook?

BROOKS: They had just written the book [*Applied Mechanics Statics*], and I used it as a textbook. At that time, there were 100 engineering students, and they had to take a certain amount of dynamics. Another thing I found out, which surprised me, was that I was told, "You give the lecture three times a week, and you do the problem-solving session"—which used to be common in those days. Did you ever have such a thing?

PORTER: We did have recitation—that's what it was called then, in Pennsylvania.

BROOKS: Well, these problem-solving sessions went on for three hours.

PORTER: It's like a lab.

BROOKS: You don't have a lab, actually. You know, there's a problem, like how to design a beam that's 50 feet long? You have a computation session, in groups, in the evening. You figure out how to do simple calculations—like how do you figure the stresses in the beam. Things like that. I enjoyed working with Housner & Hudson; their book was used for the second and third terms. I must have done well, because the next year, the second year of my graduate study, they put me back on the third-year math class, teaching Laplace transforms and Fourier analysis and things like that.

PORTER: And was it over in the math division or it was part of the engineering division?

BROOKS: No, I guess it was in applied mechanics. It was probably Applied Mechanics 110, but it was really a math class—basic math textbook with all these advanced things in it. If you were in the junior year, you got onto some pretty complicated stuff. So I waded into that, with a class of twenty students. I had to make up my own quizzes or hour exams; I did the final exams in coordination with the other instructors. Nowadays, the TAs just go to the labs; they don't actually give the lectures, except when the professor is away. This was a challenge. I figured it was a nine-hour assistantship that took me about twenty hours a week. The pay was $900 for the academic year.

PORTER: Three terms.

**BROOKS**: All three terms. A hundred dollars a month. Teaching about twenty hours a week, plus your own academic program, your research program. So I was busy.

Also, another footnote: When Freddie and I took off for California, in an old station wagon with a lot of our belongings, we had an accident on the way that totaled the car.

PORTER: Oh, no.

BROOKS: Freddie slightly injured her ankle—she had a chip in her ankle. I wasn't injured, except maybe for a bruise on the head. Somebody ran into us from behind, when we were carefully crossing a bridge.

Anyway, we worked through that. We did the rest of the trip, from North Carolina to California, by train. We got train tickets via Chicago and the Canadian Rockies to Vancouver and then down to Seattle to visit Freddie's sister, and down through Oregon by train. We got off the train at Redding so we could have a one-day field trip to Shasta Dam. On the way, I'd been studying all the dams of the Western states, which ones were interesting and accessible. I learned that it was possible to do a field trip from Redding to Shasta Dam, which is ten or fifteen miles away, something like that. They'd give you a tour of the whole thing in a car. I had sort of been fixated on big dams since I was a child. I remember learning in grammar school about a tremendous dam, Hoover Dam—a wonder dam. Just like the space-age fixation of a later generation. I wanted to go see some good dams when I got to California! In elementary school, I was also fixated by civil-engineering genius. I was really fascinated by the Panama Canal, which was built in the early 1900s. So here I was, a grammar-school kid in the 1930s, and the teacher says, "Choose something to write a paper about." I thought, "Well, I'll write about the Panama Canal."

PORTER: So by your second year at Caltech, you're teaching applied math and getting ready to start doing research.

BROOKS: That's right. One of the important decisions early on, of course, is choosing an advisor. On my short list, I had Jack McKee. He was in sanitary engineering, in those days part of civil engineering. Did you know Vito Vanoni [professor of hydraulics, emeritus; d. 1999]?

PORTER: I remember the two of you going to lunch at the Athenaeum when he was in his nineties.

BROOKS: When I was his assistant, guiding him. I liked him because he was interested in practical hydraulic structures—energy-dissipation structures, erosion control of streambanks, riverbed management, debris basins. He took me on a lot of personal field trips as soon as I got to Caltech. When there was a flood, we'd go out and take a look at what was happening, what was coming down. We quickly became aware of the fact that sediment is the so-called elephant in the room. Debris basins—and places where there weren't debris basins—and flood-control channels filled up with sediment and overflowed. The sediment just went all over the place.

PORTER: The channels aren't as deep as they should be.

**BROOKS**: That's right. Or just didn't have the capacity to move that much sediment. When you're coming off the mountains and down from Altadena—that's the alluvial fan. So it's inevitable that a large part of the sediment load was deposited in Pasadena. That's what we live on. It built up for millions of years—or at least thousands. Anyway, I liked learning about the mountains and sediments and the problems and challenges and the need to know more about how sediment is transported.

Vito was also an expert on experiments with flumes. He had a laboratory, which was taken down when the Chandler coffee shop was built on campus. Chandler was the footprint of the Sedimentation Laboratory, which was just a one-story wood-frame building with flumes in it. It was supported by the Soil Conservation Service from about the late 1930s until a little bit after the war. They stopped being the sponsor before I got there, but the laboratory was still there, where I could start my research and have a flume to myself. You probably never saw it, but you understand the concept. I liked the idea of being able to experiment with these things.

PORTER: So you chose Vanoni as your advisor?

BROOKS: Yes, and I chose civil engineering as the department. I went to a faculty meeting, I examined the requirements they had for the Master's degree, and just as I guessed, not enough mathematics. The students who came into civil engineering hardly knew how to do algebra. Other engineering schools just give you kind of an introduction—"Here's a calculus class"—but you're not expected to actually use calculus.

PORTER: Not really apply it.

BROOKS: If you look in the early catalogs, you'll notice that some of the engineering classes, other than civil engineering, were set up so if you came here as a Master's student you would take a course in structures, another in hydraulics, a course in surveying, a course in drawing. In other words, it was all sort of cookbook, laid out—this was the recipe for getting a Master's degree. A lot of programs are still like that, maybe justly so. Included in that approach, there's a lot of time spent—"OK, you'd better have drawing class today—engineering drawing—from one to four o'clock." Or you're going on a field trip to look at different structures, or you're going to have labs where you do testing. So my rationale was that this kind of program did not have enough of an analytical base to lead, for example, to a PhD-level program. This was fairly soon after I got here. I was kind of the young upstart.

PORTER: What was the reaction?

BROOKS: Well, Caltech professors are smart. Romeo Martel and George Housner said, "Well, Norm, we'll ask you to design us a better program."

PORTER: OK, there's an assignment!

BROOKS: I was flattered, honored, because they thought enough of my judgment as to what the improvement should be. I would actually prepare a first draft. We'd need a course with more mathematics, more regular fluid mechanics. I guess the other faculty liked what I drafted, and they tweaked it this way and that way. Along the way, I looked at the requirements for a PhD in civil engineering. I asked questions like, "How come you have to study surveying in order to get a PhD in civil engineering?" That's ridiculous. I'm not going to do surveying, I'm going to *hire* someone to do surveying. I don't even have to know what the surveyors are doing, because there will be other engineers, who have Master's degrees, who will supervise the surveyors.

PORTER: Did you know Ron [Ronald] Scott [Hayman Professor of Engineering, emeritus; d. 2005]?

BROOKS: I met Ron a few times, yes. He didn't come until 1958. He epitomized soil mechanics. The professor in soil mechanics before him was kind of— You do a certain amount of soil tests, and then you sign off for the subdivision or highway, and you train people to do housekeeping-type soil mechanics. They weren't training students how to understand landslides in the mountains and things like that. When Ron came, he had full competence in mathematics. He wrote a textbook [*Principles of Soil Mechanics*] with all kinds of diagrams on figuring soil stress in different kinds of ways, and he overlapped into interesting contaminants—contaminants in groundwater.

In my first few years, I had an office on the first floor of Thomas [Franklin Thomas Laboratory of Engineering] and I got well acquainted with Fred [Frederick C.] Lindvall, who was chairman of the engineering division for quite a few years after I came [Lindvall was division chair from 1945 to 1969—ed.]. I think he had an interest, more than some of the other professors, in actual engineering practices—doing consulting work. He encouraged me and others to be consultants. The idea was that it broadens the university by having professors connect with the outside, with different kinds of organizations.

The other important thing that happened in the 1950s—in 1952—was that Vito Vanoni and his wife decided they wanted to take a grand tour of Europe. This is interesting, because it seems like things happen that give you opportunities that lead to a different place. Like the fact that when I came here and found the civil-engineering program antiquated, I had the opportunity to revamp it and establish my credibility as a permanent professor—at least I got that feeling from it, right off the bat.

So Vito went to Europe. My reaction was, well, I can't start doing my flume experiments, which I had been planning to do during the summer with his guidance. There was quite a lot of technique to doing flume experiments, depending on what questions you're trying to address. I didn't feel as though I could do that. So I thought I'd find a summer job that would give me some different experience—something I advise my students to do: "Don't overlook opportunities for a second track when you're a doctoral student, because it might be very useful." So you can probably guess now what's coming. Jack McKee says, "Well, I had a call from A. M. Rawn, the chief engineer of the Sanitation Districts of Los Angeles County, and he wondered if there was a summer student who might help them think about a better way to have an outfall for discharging sewage effluent out to the ocean."

PORTER: This was very early in your career.

BROOKS: Yes, it was in 1952, so I was twenty-four years old. The term "outfall" was given to pipes that run out to the shore—maybe a four-inch pipe. You just let the water run out. On a river, an outfall might be from a mill or something—

PORTER: A direct effluent discharge?

BROOKS: Yes Run a pipe down to the riverbank, maybe ten feet out in the air. The discharge just falls out; that's why it's called an outfall. So we had a meeting. You need to ask good questions: "What are you trying to do? You have to do some real fluid mechanics, with dimensionless numbers, differential equations, and so on, to find out what would be the optimum thing to do." Now, the county already had two outfalls. They were a mile long and about six feet in diameter. At the end was a kind of three-pronged fork. The discharge came out of the pipe in a few two-foot pipes going this way and that way for a few feet.

PORTER: One going forward and two split off maybe sixty degrees or so?

BROOKS: The whole thing was only maybe twelve feet wide. It was like an "uneducated" nozzle, not much better than just dumping the effluent. So, anyway, during the summer I did some experiments, and I thought the first thing they needed to do was achieve a much higher dilution. My knowledge of heat transfer—I taught the math classes, and I'd give the students problems involving heat conduction, where you might have to use a differential equation to show how fast something heats up. Anyway, so I was familiar with the idea that if you're trying to cool a massive molten metal, you don't make a big glob, you make a lot of small ones. The cooling time is much faster, and you can calculate the cooling time using differential equations. If you make it this big, you can calculate what the characteristic cooling time is and how you can relate the actual results to a multiple of the characteristic time. So I had all this in the back of my head. Well, it's foolish to think you can get any kind of dilution just using the ocean. I also felt that the ocean is a resource—an ecological, environmental resource—not just a dump.

PORTER: Revolutionary in 1952.

BROOKS: Yes, that's exactly what I wanted it to be. That's exactly what I did, because after working on buoyant jets for a while, I tackled the fie
ld: If you go some miles offshore, and you have a source of more highly diluted effluent, then how do you know what happens next? OK, so you write some more differential equations, for the diffusion of the so-called sewage field. Just like meteorology, you have to know what the current fields are, the current frequencies, the current directions.

PORTER: And the thermocline and the halocline.

BROOKS: The thermocline. At that time, people were beginning to realize that during the summer thermocline there was less shoreline pollution. There was much more of it in the wintertime, because the sewage plumes came up to the surface. As part of my summer job, a senior engineer in the office took me on a weekly field trip. Every Friday—or whatever day it was—we'd go out with the survey boat and look at the pattern of pollution. We could observe it by eye. When you got over the end of the pipe, you'd get one horrendous boil. This was where it was about a hundred feet deep. The discharge flow comes up with a super elevation of a few inches, and then it spreads out, and, depending on the current, you could see it going this way or that. Or if there wasn't much current, it went a different way. I was observing what I call a transport process, as a chemical engineer would say. I invented the term "hydrologic transport processes," and I created a course at Caltech called ENV 112, Hydrologic Transport Processes. You could apply it to all different kinds of things.

PORTER: Yes, transport. It was a kind of more advanced fluid mechanics.

BROOKS: Her's a side point: When I went at Caltech's invitation to a fiftieth reunion class, I met some of the students I'd taught the math class to when I was a TA. I remembered one student in particular who got an A-plus—he was really smart. So I went over to greet him, and he couldn't remember who I was. That was a little bit deflating. [Laughter] Of course, I didn't remember all my teachers, either.

PORTER: The hydrologic transport processes are going to play a very large role in your consulting work in San Diego and Boston and so on.

BROOKS: And on my research program, too. I had a two-track research program. Going back now to Vanoni being away for a summer: While he was gone, I got interested in ocean pollution. The chief engineer of the Los Angeles County Sanitation Districts was interested in it too—that's why he called on Dr. McKee, because McKee had done some experiments around 1930. Of course, in 1930, they didn't have any way to measure dilution—like how many parts of sewage to how many parts of wastewater. You can do it with dye—dye contrast and things like that, and maybe you could measure change of salinity. But it was rather crude in terms of the— Well, you could measure the flow rate by trying various-size nozzles, but the chief engineer wasn't thinking about multiple nozzles. He just asked, "What if we use a twelve-inch nozzle instead of a twenty-four-inch nozzle?"

PORTER: A single device.

BROOKS: Yes, a single-device nozzle. But also, he didn't know about fluid dynamics, dimensionless numbers. He didn't know about the Reynolds number and the Froude number, depth ratios, and things like that as critical elements in a rational analysis, even for a single-device nozzle. So I wrote up a report at the end of the summer, and he was very interested in it, and so was my supervisor. So we got together and wrote a paper for the ASCE [American Society of Civil Engineers]. It was called, "Diffusers for Disposal of Sewage in Sea Water" [ASCE, 1961], by Rawn, Bowerman, and Brooks. The twenty-four-year-old me was the last author, and the chief engineer was the first author, and the staff supervisor was the second. It wasn't quite that way, because the second person [Frank R. Bowerman] was the one who was observing the effect of temperature, so he prepared the part of the paper describing the thermocline as part of the natural environment. We hadn't actually built the improved diffusers for outfalls by then. This was a paper using my summer work, the field work of the staff engineer observing the boil coming up, and the temperatures, and then Rawn, the chief engineer, realizing the value of getting something going. Rawn probably sensed that you needed to bring the right science into the picture. After I did that summer work for them, they retained me by the month for maybe ten or fifteen years.

PORTER: A long monthly contract.

BROOKS: What I mean was, they paid me a monthly fee of $150 to be available to answer questions or come to the office to look at some of their drawings or whatever they were doing, like connecting two different channels or pipes, or other things. So I did go in occasionally. If you've ever seen pictures of what engineering drafting rooms looked like in the 1940s and 1950s, there would be row after row of drafting tables and maybe a dozen draftsmen, drafting. No computers. And the head draftsman would say, "Uh-oh, here comes trouble again! Every time you come here, you mark up all my sheets." I could see all the things they were doing that weren't good for energy conservation or smooth flowing—for example, when it came to designing a pipe with holes in it, rounding the entrance to the holes was essential to get a good jet coming out. But he was good-natured about it. It sort of amused me.

PORTER: You said you had a two-track research program. The diffusers were one and the other was—

BROOKS: Sediments.

PORTER: Sediments. There's a story I've heard about your early results, physical results, in a sedimentation experiment, and your asking Vanoni—

BROOKS: OK, I'll tell you that story, because it's part of my PhD thesis.[1] This is why Vanoni was a great advisor, as you'll see in a minute. When he came back from his trip

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[1] Norman Herrick Brooks, "Laboratory studies of the mechanics of streams flowing over a movable bed of fine sand," Caltech PhD Dissertation, 1954.

to Europe, I was trying to do experiments in the flume. One of the things I wanted to do was to have a turbulent flow over the sand bed and then take samples at different levels and prepare a concentration profile in more detail. Since you come from engineering, you know what profile means. I was taking samples with something like a Pitot tube—sort of a tiny suction tube. You suck in samples at different levels. You do this to explore different flow rates. This was, in a sense, almost an expansion of Vanoni's PhD thesis, in which he developed the first equation to predict the distribution of concentration over depth of the flow.[2] And he got his inspiration for doing his thesis from [Theodore] von Kármán. Von Kármán was on his thesis committee and was very interested in seeing him start developing detailed models of suspensions of sediment. Do you know about the Von Kármán boundary layer equation?

PORTER: Yes.

BROOKS: That's what we use. You can imagine the conversation—Von Kármán saying to Vanoni, "Well, you just take water in a flow, just measure the velocity profile and see if it fits my law, the Von Kármán constant, and then write some differential equations where you've got the flow going horizontally and you've got the sediment distribution vertically due to settling but being re-suspended by turbulence from the boundary." It was sort of moving the whole von Kármán boundary layer into the sediment layer. So a lot of that early detailed look at sediment behavior was motivated by von Kármán's conversation with Vanoni. Also it put us ahead of other universities, which hadn't gotten around to looking at the turbulence structure or the concentration distribution within an organized turbulent shear flow.

Hunter Rouse—do you know that name, Hunter Rouse, of the University of Iowa? He wrote a lot of textbooks. He built a turbulent jar, in which a dish would go up and down like this, and he made a suspension of sediment with fall velocity, so, again, you could provide the right differential equation to write the fall and turbulent diffusion upward and the erosion at the bottom. That fitted nicely with the turbulent diffusion

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[2] Vito Vanoni, "Experiments on the transportation of suspended sediment by water," Caltech PhD Dissertation, 1940.

model. Hunter Rouse wrote a very nice book about this, and a notebook with all the details: how to process, how to take the wet samples, dry them carefully on filter papers and then weigh them on an analytical balance to get them measured down to the hundredth of a gram, a very small concentration. So anyway, to get to the punchline: I told Vito Vanoni, “I’m having a huge problem, because I cannot make the sand bed stay flat. It keeps making all these dunes and ripples, and it’s messing up my ability to take profiles.” And he had a wonderful response; it was prophetic. He said, “Norman, I guess that’s what you’d better study!”

PORTER: I think that will be our next chapter.

BROOKS: I’ll just say one more thing. He was a very curious man. Maybe he did his experiments in the big flume and didn’t use a sand bed but just a small amount of sand, with an artificial roughness amount of sand glued to the bottom, which had a defined roughness and didn’t move at all. So I think he was curious, he was mischievous, and that’s why he said, “Well, that’s wonderful! Have your thesis include this.” [Laughter] And then, of course, the other Vanoni course, I can tell you more about that. I found in my experiments a kind of non-uniqueness in sediment transport. You get multiple solutions from conditions you think would be definitive. In other words, there’s a solution with dunes at a certain flow and the same slope with the same discharge. Then there’s another solution with a flatbed that has a different roughness, different velocity, different speed characteristics and the whole thing. The Missouri River makes dunes; when the floods come, the dunes will flatten out, the roughness goes down—

PORTER: And everything moves downstream.

BROOKS: The stream gauges haven’t figured that out. That’s the essence of my contribution, which we can talk about in more detail. And Hans Albert Einstein couldn’t believe that was proof— Do you know the name Hans Albert Einstein [hydraulic engineer; son of Albert Einstein and Mileva Maric; at Caltech 1943-1947, then at UC Berkeley—ed.]?

PORTER: We actually have a couple of technical reports by Hans Albert when he was here.

BROOKS: Since we're talking about the vicissitudes of Vito: Do you know what he said? He said, "Norman, you'll have to go up to Berkeley and sit down with Hans Albert Einstein and explain what you did, why you're sure that you're right." And I did that. That was quite an interesting experience. I sat practically the whole day with Hans Albert Einstein, showing him that some of his conclusions or assumptions of uniqueness were false.

PORTER: That's a good thing. That's how progress is made.

BROOKS: That's right. So anyway, I like the idea that Vito thought a twenty-six-year-old graduate student could go up there and explain to one of the leaders in the business why he was wrong. Of course I behaved myself wonderfully, I just showed him how I could use his formulas and test for non-uniqueness and show that there actually could be multiple solutions for certain boundary conditions.

Before we go, I really enjoyed this discussion with you.

PORTER: It's been good. I'm looking forward to the next session.

BROOKS: It's also looking back a long way—before computers, before all kinds of digital printers, before copying machines. [Laughter] Before digital analytical balances. It sort of amuses me that students nowadays will say, "How could you ever get that done?"

**[[Tape ends]]**

**NORMAN H. BROOKS**

**SESSION 2**

**June 11, 2018**

PORTER: Good morning. Last time we spoke about your childhood up through deciding to come to Caltech, your time at Harvard, meeting your wife, all the way through your research for your PhD. Now, after you got your PhD [1954], how did you come to join the faculty at Caltech?

BROOKS: It was an interesting evolution, because when I first came to Caltech, in 1950, I had a teaching assistantship for two years. I think the faculty felt I was really a very good teacher. I participated in making exams and grading students, and I worked with various professors. In my third year as a graduate student, I had an NSF [National Science Foundation] fellowship. In the fourth year, the question of how I was going to support myself came up, and they said, "Well, we'll make you an instructor."

PORTER: The first step on the faculty ladder.

BROOKS: That's right, a voting member of the faculty. That was in 1953. Now, when I was an instructor, I didn't just sit there and do the same thing I'd been doing for the sections. I originated a couple of courses.

PORTER: Right. Last time we touched briefly on that. You felt that the civil-engineering course work was under-represented in its math—or was deficient in the mathematical foundations.

BROOKS: A little more than that. I also thought they didn't have enough hydraulics courses. For example, I originated a term-long course on groundwater flow, which wasn't dealt with at all in the existing curriculum, although it was a very important part of our hydrologic system. Hydraulic engineers have to pay attention to what's under the ground. Caltech didn't have a course on general principles of the hydrologic cycle or even—which I included—what's special about the hydrology of Southern California. You come here as a student, you look out there and see the mountains and the flooding. I wanted the students to start thinking, "This is where we are. What's happening?"

Also along in there, Frederika's grandmother moved to Pasadena, because Frederika's parents had moved from Boston to Seattle, and the grandmother didn't have anywhere to go. In Boston, she was living by herself in a small apartment, so Frederika said, "We'll take care of you. Come to Pasadena." We rented her a nearby one-bedroom apartment. Around the time I completed my degree, Frederika was pregnant. We were nicely settled in a rental house in Pasadena, kind of a cottage, and so I never thought of conducting a big search for where's the best place for me to go after I get my degree. Staying here would be a very convenient thing to do. [Laughter] I came to like that idea, and Lindvall was the division chairman, and those were the days when you could hand out instructorships without having to go through a lot of committees and stuff. So when it came to the question of what was I going to do after my PhD, the answer was, "Well, we'll just continue with an assistant professorship for a while." The rest is history. I always felt very well accepted by faculty members. I worked with George Housner on one class and Harold Wayland [professor of engineering and applied science, emeritus; d. 2000] on another class. Also I think it was clear to the faculty that I had interests extending beyond the classroom. While I was a graduate student I had served as a consultant to an engineering organization, and I was also interested in doing field trips with Vito, and sometimes with students. I was sort of *acting* like a faculty member, transitioning without actually having crossed the line. And then I started going to lunch at the Athenaeum every day. The lunch was only eighty cents then! [Laughter] So I think it was a very smooth transition.

PORTER: So the civil engineering group was now George Housner, Don Hudson, Vito Vanoni, and Norman Brooks?

BROOKS: It was also Romeo Martel, he was still around; he was the head of structural engineering. And also Mac [Caleb W.] McCormick, who was a younger structural person; he left quite a while ago.

PORTER: And Ron Scott.

BROOKS: Also Ron Scott and Jack McKee. When I first came, my choice of an advisor was between Vito Vanoni and Jack McKee, and I chose Vito, who was doing things that were more interesting to me.

PORTER: The civil engineering group then kind of branches out from Thomas, and the money for Keck is acquired, and the W. M. Keck Laboratory of Hydraulics and Water Resources comes into being. How does this happen? How does the money come in?

BROOKS: One of the first triggers was the space that had been occupied by the Sedimentation Lab, which overlapped into the footprint of the cafeteria. The site of the cafeteria itself used to be the old dorm; it was just a wooden frame building with a little alley in there where the bookstore complex is. OK, so the footprint of the Sedimentation Lab extended from the driveway coming in from San Pasqual, and there was probably a thirty-foot parking area, loading area, in front of the Sedimentation Lab. The Sedimentation Lab extended about a hundred and fifty feet into what would now be the outer portion of the cafeteria. A cafeteria was urgently needed, and the Sedimentation Lab was one of the old wood-frame buildings, which were gradually being phased out. So we got the feeling that we had to move. Also, in the postwar period there was a lot of building going on anyway.

PORTER: Right, Thomas got a little more than doubled in size.

BROOKS: Yes. I arrived here as a graduate student just as the doubling was being finished.

PORTER: I understand that that was the first new construction on campus after the war.

BROOKS: Really?

PORTER: The first real building, yes.

BROOKS: Anyway, so, given the opportunity to have a new building, I said, "OK, let's really do it right! Let's really have a good place." Of course, we were only one third of the new building. We were only one third because there was also Jack McKee, who was also in an old wooden-frame building, along the Olive Walk. They wanted to get rid of those and put some more dormitories on both sides. So he wanted this new lab, too. He didn't really have a decent lab setup, with utilities doing wet research and so on. I don't know exactly what the motivation was for materials science, the third part. I think they were expanding and were overcrowded. I think they were in the basement of Thomas.

PORTER: That's Pol Duwez [professor of applied physics, emeritus; d. 1984]?

BROOKS: Pol Duwez, that's right. So there were three groups looking for space, and of course, I said I wanted to take the bottom space, the sub-basement.

PORTER: Water flows downhill.

BROOKS: And also the loads are too heavy to put on an upper floor. So we got one-and-a-half floors: the sub-basement—except for an underground extension for materials science—and half of the basement level. Now, I didn't just regard that as space. I said that I wanted to design the best flume that anybody has in the United States. And one of the things I learned from Vito Vanoni is that there are tremendous advantages to recirculating flumes. If you're doing an experiment on sediment transport, you're not just going to put in the sediment at the front end and take it out on the back end and start with a new bunch of sediment. Vito was the first one to make high use of a recirculating flume for sediment-transport research, where you actually re-transport the sediment back to the beginning.

Now, the other thing that was new is that we carefully considered the fact that the purpose of research with sediment transport, or anything else that has a boundary layer effect—the boundary affects the flow. The flow goes slower near the bottom, and that has a significant effect on how sediment is picked up.

I don't know if I mentioned this before, but Von Kármán had a big influence on fluid mechanics, because he was involved in discussions with Robert Knapp [professor of hydraulic engineering; d. 1957], and Knapp was the one who had the idea to have a separate Sedimentation Lab, paid for by the Soil Conservation Service, doing detailed research on boundary layers in conjunction with suspended sediment transport, which was kind of a new field. It's not just a matter of looking at the flow, it's getting in there with probes measuring the velocity distribution, measuring the sediment-concentration profiles, so that you can do some integration; you can analyze the resistance of the flow and so on. Now, the Sedimentation Lab had a long sediment flume, and it had some deficiencies. One was that it wasn't long enough; it was something like sixty feet. It's really hard to get rid of the inlet and outlet effects to have a decent—

PORTER: Undisturbed flow.

BROOKS: From the middle. OK, that was one thing. The other thing that was a problem was that it was very tedious to change the slope of the flume. There were separate jacks along it, so you had to go along and crank them up and down in the right proportion. In a series of experiments, you'd have to do a whole bunch of experiments at the same slope, because it was so much work to change the slope. The cure for that was that we automated the change of slope for the new flumes in Keck. We had four jacks, and we designed this, with the help of a graduate student and Dino Morelli, a mechanical-engineering assistant professor who specialized in machinery. We designed a scheme where when you push the slope button, it would make the right ratio—I mean like one, two, three, four. So the thing would move up and down without distorting itself. That was invaluable, because you could ask, "What happens if I change the slope slightly differently, maybe 0.002 to 0.0025, or whatever. You had control of that, and you could control the depth by the amount of water in the flume, so you could actually do experiments with the same flow of water and the same sediment but changing the slope. Because that's what rivers are doing all the time—they're changing their slopes.

Remember that I mentioned that it was hard to get the entrance right. We made a special study of the best way to introduce the flow at the beginning: What's the shape of the inlet, starting under the flume to enlarge the flow, to make it turn the corner nicely without extra turbulence and come up and turn around another corner? I won't go into details, but we thought it was so important that we made a model study of the inlet for the big flume by attaching the same inlet shape to a small flume, just to learn how to make changes. We made a dual-flow-capacity arrangement, so you could have high flows and low flows of two separate pipelines. You had a special inlet at the end of the tank, so you could either have an overfall or you could have the level control right out to the end of the collection tank, so it would be smooth right up to the beginning.

PORTER: So the hydraulics group from civil engineering has now moved into the new lab in the Keck building. How does your group evolve into the Environmental Engineering Science option?

BROOKS: OK, let me say a little bit about the teaching part of it. When I developed the course called Hydrologic Transport Processes, I borrowed a term from chemical engineering, which you probably know well: "processes." The idea was to combine the concepts of transport theory into the hydrologic environment, which people just hadn't seemed to do. They seemed to think, "Well, there's so much water coming from here to there . . . ."

PORTER: And it's the simplest possible representation—it's all water, on a smooth bed.

BROOKS: Yes. So one of the first PhD theses done at the new lab was the transport of pollutants in a streambed, with bedforms such as sand dunes. Suppose there's a spill at a certain place on a river. What happens to that spill as it goes down the river?

PORTER: A chemical spill.

BROOKS: There's a wastewater process called longitudinal dispersion. That means that because of the velocity profile in the river, if you introduce a passive pollutant it will mix vertically, because of the vertical turbulence, and it will then get differentially transported, because what's on the surface layer goes faster. So this means the cloud is dispersed, but it keeps dispersing more and more, because the back end, where it's in higher concentration, is still mixing up toward the surface. This is a very important concept, and it happens in the atmosphere, too: Smoke from a forest fire has a longitudinal dispersion, because it mixes up and down; the upper part goes faster, so the cloud gets bigger.

Have you heard the name G. I. Taylor? He was a hydrodynamicist in England. He promoted the analysis of longitudinal dispersion in pipelines. Taylor gave a seminar at Berkeley when my former student, Hugo Fischer, was an assistant professor there. Taylor said, "It'd be wonderful if somebody would do that open-channel dispersion for a stream." Hugo said, "Oh, I already did it!" [Laughter]

OK, back to my teaching. I taught my students how to predict longitudinal dispersion, how to predict jet mixing—shooting out of a jet into the ocean. I developed a term—"environmental hydraulic engineering"—to try to specify that.

PORTER: Starting to encompass industrial discharges into rivers as well as—

BROOKS: All kinds of things, even mixing inside sludge-digestion tanks. There you do it by bubbles. I did some work in Switzerland with a university there—on the vertical mixing in Swiss lakes by bubble plumes. In other words, you actually can modify your environment at the same time you're using it. If you're having a cooling-water discharge into the ocean—

PORTER: Thermal plumes and thermal diffusion.

BROOKS: Yes, but you didn't mention one of the important ones—jet-induced advection. You have a line diffuser, maybe it's a thousand feet long, but you have a bunch of nozzles on it, coming out at an angle, and they're all pointing in the same direction, so the combined momentum of maybe sixty different jets, maybe as big as twenty inches in diameter—

PORTER: —begins to generate a current.

BROOKS: It generates an offshore current that self-flushes the site. It pushes the heated water out, away from the shore and into the coastal current. At the same time, the cooler water comes back to the site. This is quite a novel idea. People before would say, "Well, you make a jet, you just put it out in the water, and that's it." "No," I said. "I use the jets, in the sense that I move to an environmental hydraulics, where I'm actually paying attention to—

PORTER: —the water after it leaves the jet.

BROOKS: That's right.

Part of being a faculty member in civil engineering is, you participate in the ASCE. In the hydraulics division, I gave some papers there about my research and so on, but I noticed that in the history of the hydraulics division it was like, "OK, how do you design a better Venturi meter?" Or what do you do if you want to build a canal, or a pipeline, or a reservoir? There was no overall committee to look at the context of what you were doing. So I proposed that we should have a committee on hydrologic transport of pollutants, like a spill in a river. That suggestion was accepted, and I was the first chairman, and that was OK. The committee did some interesting things to draw attention to papers on those kinds of subjects. And you know what the result of that was? There were many more committees formed which had an environmental context. I look at the programs of the ASCE hydraulics division now, and I would say that half of them relate to environmental hydraulic engineering. They've stepped away from just "Build a canal" or "Build a dam" to really examine how that would affect the quality of the water.

PORTER: Moving beyond just structures.

BROOKS: Moving beyond just structures, that's right. This was falling in line, also, with increased use of electronic devices in laboratories and in the field, so the work could be done much more effectively than before.

That was sort of my way. If I'd have proposed to the ASCE, "Let's have environmental hydraulics," there would have been a big argument. Instead, I chose a topic, and it seeded itself. [Laughter]

Anyway, some of this is background for why I wanted to have a Keck lab with a really good flume—and some smaller flumes and other things, too. There was no problem getting it approved by the institute. They provided the money. I had a major role in designing the new flume, because Vito Vanoni was ill for a period when we were doing some of the detailed design.

PORTER: This is in the late 1950s?

BROOKS: That's right. So I really supervised the layout of the new flume. And of course I'd go to Vito's bedside and tell him, "This is what we're doing." But anyway, for the whole laboratory I essentially decided what to put in different places and what spaces to have for this and that, with support and help from the architects and the Caltech people. I made it clear what ideas I had for the arrangement in the sub-basement: the tanks, and spaces under the floor, which were necessary for returning water to the flume. The other groups had similar ideas for driving ahead with new technologies and new capabilities, so that's why the Keck Laboratory of Hydraulics and Water Resources got the support it needed.

That name was important, because I wanted people to think about hydraulics, not just hydraulic engineering—that could be gas-station lifts. I wanted people to think about how hydrology would help us with our water resources—hydrology and engineering. Which our group was the epitome of. We were all working on things that were useful in different contexts, all in connection with water resources, whether it was flood control or coastal engineering.

PORTER: OK, so you and Vito and Jack McKee from civil engineering are now collected into the Keck lab. How does this faculty core grow?

BROOKS: It was more a matter of what's important in acquiring students. I worked on admissions in civil engineering, among other things, and I noticed that it's almost impossible to attract a student who has a developing interest in environmental matters to go into civil engineering. Because if they're interested in the eutrophication of lakes or any number of such things, civil engineering doesn't convey the idea of doing anything for the environment. That's not true, but I'm just saying that if somebody in high school says, "I want to be an environmental engineer," you don't hear them say, "I'll go study civil engineering."

PORTER: Right, because civil was structures.

BROOKS: Structures and building things, transportation, and of course in the days of the Romans, it was building—

PORTER: —aqueducts!

BROOKS: [Laughter.] That's right. So I felt very much the need to have a label that would attract those students who had a science background or a mathematics background to come to our program and take courses and come out of the program either feeling like a scientist or like an engineer.

PORTER: OK, so they could do either or both.

BROOKS: I was using myself as an example, because I majored in math at Harvard, and I decided I'd do civil engineering.

So right away, when we established the Environmental Engineering Science program, or EES [1969], we got a flood of applications. And in other places, like MIT, they were changing themselves to "civil and environmental engineering." In fact, I changed my professorial title to “environmental science and civil engineering.” By doing all this, we attracted other faculty, from other fields, to participate. You could have a course in environmental economics, because there might be students in the EES program who could take that course as part of their degree—because the degrees were given by the divisions. The divisions still controlled the examining committees, and they still fit the courses into the divisional goals. But if a student wanted to do a thesis on the marketing of water, they’d have a ready bunch of people to talk to. The whole idea of Environmental Engineering Science—EES—was to emphasize the role of science. I wanted engineers to be trained like scientists. Environmental engineering science can deal with ocean cooling, acid fog, ocean disposal, lead in the environment, and all kinds of things.

PORTER: Mercury in fisheries was a big topic.

BROOKS: Yes, that’s right. My basic paradigm was, if you can get more science, all kinds of science, into environmental education, you’re going to have better results. And I liked the idea of having some students thinking, “Well, I’m primarily going to be an environmental scientist, I’m not going to go out and design treatment plants.” And have them sit down with people in offices. And maybe have other students thinking, “I’m primarily going to be an engineer and work on better ways to treat sewage,” and have them sit next to somebody who’s interested in economics or public policy. Because they educate each other. I thought that was very important.

Before EES, there was a certain protocol enforced at Caltech, which said you had to be in one of the six divisions and you owed your loyalty to them. You didn’t go out and work with professors in other divisions. This wasn’t so much deliberate as it was just “We’re counting on you to carry our story to the outside world.” So when we wanted to set up this program, there was quite a lot of resistance in the faculty. They’d say, “Well,” all the things you’re trying to do, the divisions already do, in their own way.” And I said, “The point is, you want to make it easy for students and professors to work *across* divisions without a lot of administrative fuss. If you want to be associated with the EES faculty, you don’t have to give up what your association is now. You still have your home-base division, and we're not trying to take anything away from that." The idea was not only to be open to making environmental hydraulic engineering a recognized field but also to create a whole field where environmental studies would be more and more combined.

PORTER: Big picture, holistic approach.

BROOKS: Or a student might want to do geomorphology. There's one I can think of—he came to the Keck lab to do a set of experiments because he didn't have the facilities or the right supervision to do them under Professor [Robert P.] Sharp [Sharp Professor of Geology, emeritus; d. 2004]. So EES allowed the geomorphology students to be more multidimensional, and the reverse happened, too. Another example: Chemistry students loved to come and do environmental chemistry, but they didn't want to be in the Chemistry and Chemical Engineering Division, because they wanted to be thinking about chemistry issues in the environment, like water chemistry and what was going on there. Jim [James J.] Morgan [Goldberger Professor of Environmental Engineering Science, emeritus; d. 2020] was perfect for that. You don't have to be a civil engineer, get a civil engineering degree—you can get an environmental degree, which makes you marketable.

PORTER: Right.

BROOKS: I wanted to get the word "Science" into the title, and that idea was borrowed from Harold Wayland, who had a program called Engineering Science. I thought, "Well, that's too vague." I wanted to use that concept, engineering science—

PORTER: —but focus it a little.

BROOKS: Yes, focus it on the environment. When they later changed the program, they reversed it, and now it's called "Environmental Science and Engineering." But they've still got the "Engineering."

PORTER: You bring in Jim Morgan doing chemistry of natural waters.

BROOKS: Yes.

PORTER: Which is chemistry, but in the environment.

BROOKS: Yes. Put it this way: In conducting this program—I was head of it for different periods—you try not to define what it's supposed to be, because you want the students to come and say, "Oh, I want to do this or this." I'd say, "Fine!" The EES program was actually part of the engineering division, but we provided course material and research experience so that they could step outside that boundary.

PORTER: And you had Fred [Fredric] Raichlen [professor of civil and mechanical engineering, emeritus; d. 2015] come in, who was in coastal structures and coastal dynamics?

BROOKS: Yes, but also some basic fluid mechanics, laboratory techniques, recording waves and velocities.

I also want to take the opportunity to mention that not only did we have the regular faculty members but also senior research faculty, like Robert C. Y. Koh. Did you know him at all?

PORTER: No, but I've seen many of his publications over the years.

BROOKS: He got his undergraduate degree at Caltech, and he was one of my PhD students, back in the early 1960s. After he finished his PhD[3], he stayed at Caltech as a research fellow. He and I did many consulting jobs together. He was very helpful to students too, especially at the beginning of using computers—he helped students get their calculations organized and done. Also, he did research in a field of environmental

[3] Robert Ching-yee Koh, "Viscous stratified flow towards a line sink," Caltech PhD Dissertation, 1964.

hydraulics called selective withdrawal from reservoirs. If you can visualize it, a reservoir is actually a stack of water with various chemical compositions.

PORTER: Right, it's stratified.

BROOKS: Stratified. In other words, there are different temperatures, different densities. You can cut a dam with multiple depth outlets, so you can actually control to some extent the temperature you want the discharge to be. But stratification traps pollutants; it interferes with the downward diffusion of oxygen. So, like in the Swiss lakes, you get anoxic patches in reservoirs, because you don't have vertical transport. You go down a hundred and fifty feet, it's pretty much insulated from vertical downward diffusion of oxygen. On matters like this, we had a lot of interaction with Jim Morgan. One of my PhD students did a thesis on mixing of lakes by induced vertical mixing—just pumping the water up and down. So, OK, let's get back on track here.

PORTER: You also brought in Wheeler North [professor of environmental science, emeritus; d. 2002], who was exploring the kelp forests off the California coast. One might think he was in biology.

BROOKS: He had quite a bit of engineering in him, too. One thing he wanted to do was establish floating kelp farms offshore—to expand the areas in which we can grow kelp, for food or energy. I'm sure he profited from discussions with Fred Raichlen and me to the effect that the logistics would make such a farm impractical. It wouldn't be on a big enough scale to be worth it, because the ocean currents would tend to move something that large, and then there's the logistics of port facilities—going back and forth to it.

So we had interactions like that with Wheeler North. I had students who wanted to learn about environmental biology. He taught courses that covered other things, too, like bacteria and marine growth.

I think the faculty was mostly favorably impressed with the EES option, but it was a little disappointing that the division didn't really put that much into it. We were told that when we established the option we'd have to sort of do what we could with the faculty we already had. It's not like we were expecting to hire six new professors or anything like that. That wasn't the way I wanted to do it anyway—I wanted it to be something that expands—a network of interactions with different people. Did I mention the Special Laboratories Committee of the faculty?

PORTER: No, you haven't.

BROOKS: In 1971, I chaired a committee on interactions between JPL [Jet Propulsion Laboratory] and the campus—middle-management-level people from both the campus and JPL, appointed by the Caltech president. That was an interesting committee. We wanted JPL to be more involved in providing academic opportunities for faculty and students. One of the obstacles was that JPL was doing a lot of classified work at that time. You couldn't even get through the front gate unless you had a badge. Well, that was relaxed, so it was possible for people to go back and forth more easily. But we also recommended that JPL refrain from adopting the Stanford research-center model. Don't become a think tank; stick to what's actually related to what you're doing and what can relate to the academic program of Caltech. Because they'd been taking ventures into various fields like waste treatment and police surveillance with helicopters.

PORTER: They also did some solar-collector work, early photovoltaics, under an ERDA [Energy Research and Development Administration] contract. But photovoltaics definitely played a huge role in the space program.

BROOKS: Yes, but I meant things like using systems analysis to improve wastewater treatment—that didn't fly.

PORTER: I can see that.

BROOKS: So some people on the committee gently said to JPL, "You're very good at doing what you're doing, and keep doing it, but make more opportunities for students." And I think just getting rid of all that classified stuff was good.

PORTER: You had John Seinfeld [Nohl Professor and professor of chemical engineering], in chemical engineering, affiliating with EES—

BROOKS: Yes, that's right. Some of his students wanted an EES degree rather than one from chemical engineering.

PORTER: Was Glen Cass an EES student or was he a chemical engineer?

BROOKS: I was thinking about him the other day. [Glen R. Cass, professor of environmental engineering and mechanical engineering; d. 2001] I think he was an EES student, but when he got his PhD he became a faculty member in engineering. The engineering division told him that if he was part of the engineering division he'd get some lab space in Keck.

PORTER: His thesis was a lot of fieldwork—data collection [on air pollution] throughout the LA basin.

BROOKS: He did his thesis through EQL, because it gave him more contact with the companies that were making the smog.

PORTER: EQL—the Environmental Quality Laboratory—was intimately affiliated with EES but it arose out of the president's office?

BROOKS: Yes, I'll tell you about that. Let me say another thing about the Special Laboratories Committee: There were faculty objections to establishing new programs. They did not like to change the pattern that had been developed; they said, "You're being un-Caltech like, you're destroying the flavor of Caltech." But I was able to fertilize cross-connections, and even more so at EQL. We had to break down this idea that you could have other units doing work besides the division. Since then, there have been a lot of these little institutes of this or that established.

PORTER: There's the joint-option computational neural systems, between the EE [Electrical Engineering] option and the biology division. You've got the Caltech Center for Environmental Microbial Interactions, CEMI.

BROOKS: I think I broke the ice a little, because none of those kinds of things ever existed before EQL.

PORTER: Let's talk about EQL. You were experiencing rigidity between the divisions. And so the president—was it Harold Brown [Caltech president 1969-1977]?

BROOKS: Yes.

PORTER: How did Harold Brown decide to create a cross-divisional laboratory?

BROOKS: No, let me explain it to you. EQL should not be considered cross-divisional, it's extra-divisional. It was established in 1971 by Harold Brown, and Lester Lees [professor of environmental engineering and aeronautics, d. 1986] was the initial director.

PORTER: Lester Lees from aeronautics?

BROOKS: Yes, and he did the job for about four years, and then I took over. Going back to Harold Brown: I first met him when he was secretary of the Air Force; I was one of the people who interviewed him during the presidential search. Anyway, when he came here, he said, "How come you have all this smog and nobody's doing anything about it?" So he mandated that we should establish an EQL and find a professor to direct it. In other words, he didn't go through any faculty procedures to approve it.

PORTER: And he didn't hire any new faculty.

BROOKS: He didn't appoint any new faculty. He just said, "You can appoint the people you need—staff people—under my jurisdiction." And it was all focused on air pollution, it didn't have anything to do with energy or water.

PORTER: Right. The first publication was "Smog: A Report to the People." [4]

BROOKS: Yes. Now, I haven't looked at it recently, but my reaction was that it was a very good educational piece, but it didn't move us any closer to solving the problem.

PORTER: It framed the problem.

BROOKS: That's right, it made people aware. Lester Lees appointed some people who were very good and some who wouldn't have been approved by the faculty as research fellows. I don't want to go into EQL history, except that they developed a good fund-raising pipeline, so when I took over, there was money coming in. And Harold Brown, also, I think, made a mistake, because he wanted the EQL to advocate policy. Well, if you establish a research organization, you don't want to be an advocate, like: "Southern California, you should do this," or ". . .you should do that." That was kind of against Caltech policy.

PORTER: Lobbying is a federally dicey proposition for nonprofit groups.

BROOKS: Yes, that's right. And even saying, "I've studied the problem, and you should make decisions like this"—that's really lobbying. When I took over, there were some things I changed. One of the rules was, we stick to policy studies, not policy recommendations or advocacy.

PORTER: Cap-and-trade and the capture of gasoline vapors at fuel pumps were just a couple of the projects that came out of EQL.

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[4] https://authors.library.caltech.edu/25739/1/EQLReport4.pdf

BROOKS: Yes. There was a cap-and-trade for water resources, but that's a different matter—I don't want to get into that. But I want to say what happened when I took over. I was not enthusiastic about EQL when it was first established, because I thought it was too far away from the Caltech mode of doing strong science. They weren't doing strong science, they were doing empirical stuff, and also they were being kind of an advocacy group and appointing some people who didn't have expertise in the fields they were studying. They did interesting things in geothermal energy; I'm not belittling them. I'm saying that this was how they worked, which made the faculty kind of nervous.

I established an EQL executive committee, and I appointed unquestioned science or engineering experts, and Roger Noll [professor of social science, 1965-1984], an economics expert. There was John Seinfeld, myself, and I don't remember if John List [professor of environmental engineering science, emeritus] or I was doing the water part of it—that changed from time to time. Anyway, the appointment of John Seinfeld came about because I attended— He was a young professor then, from I think it was Princeton.

PORTER: Princeton, yes. He came in the late '60s.

BROOKS: I went to one of his seminars, where he talked about atmospheric diffusion and reactions, and I said to myself, "That's the kind of research we want to do at EQL." We wanted to find out what was happening in the atmosphere, where the pollutants were coming from, what quantities, and so on. So I made him the lead person for air pollution. I agreed with the idea that you had to make a scientific analysis of where smog is coming from, how it's reacting, and where it's going, in order to control it. The first thing we needed was a meteorologist, so I hired a meteorologist. And also I decided that the staff people should consist of professors, students—graduate students primarily, and research fellows, the idea being that if you're a research fellow or a postdoc you could only stay there five years. I had an enforced rotation, because I thought the value of EQL rested on the fact that when you got a new research fellow you got a new bunch of ideas.

PORTER: Roger Noll was from the Division of Humanities and Social Sciences. Was he an economist or a political scientist?

BROOKS: He was an economist. He was very much up on cap-and-trade or other price incentives to do things.

PORTER: And Jim [James P.] Quirk was another economist from HSS who worked with EQL?

BROOKS: Jim Quirk, yes.

PORTER: And what kind of political scientist did you have? Because policy is part of what you were studying.

BROOKS: Well, I had Jim [James A.] Krier. He was a law professor at UCLA, interested in environmental law. He would say to me, "Norman, just because you pass a law doesn't mean it's going to happen." [Laughter] I collaborated with him on a book project for NOAA [National Oceanic and Atmospheric Administration]. There were some other people in political science who came and went. I can't remember all their names right now. Of course, John Ferejohn [professor of social science, 1972-1983]. Is he retired now? He must be.

PORTER: I believe so, yes.

BROOKS: He was quite interesting. So I put the management in the hands of people who were obviously well qualified and that helped to get us money from companies. We got a lot of money from Union Oil. I insisted that we weren't going to advocate regulations, but we'd make it clear what the result of regulation A, B, or C would be. And we didn't try to analyze what Texaco or Union Oil were proposing. We just said. "We're giving you our analysis of the problem, and the policy options that make sense, and you can do things any way you want." As a sideline, one of the first things I did when I was at

EQL—at that time, I was not known for being an air-pollution specialist, so I went to see the vice president of Southern California Edison. I told him about Glen Cass's research, and that he'd be interested in Glen's analysis of sulfates. It was coming in huge amounts from power companies because of the fuels they were using, and it was affecting a wide area. He said, "Oh, no, that's not true. We don't have a sulfate problem." But I found out that later, when Glen Cass's thesis[5] came out, he [the SCE vice president] put a large staff to work studying every inch of this 800-page thesis. And they spent a lot more effort studying it than whatever the total effort was in producing the thesis. That told me the value of EQL, because there wasn't a single recommendation in that thesis. Glen said, "This is where the smog is coming from, this is how much is coming from automobiles. . . ." So this is an example of how policy studies worked out, compared to policy recommendations, and also how to get a big dose of science into the whole process so that people can't say, "You don't know what you're talking about."

PORTER: You brought in political science and economics to go with the science and engineering. That's a pretty complete package.

BROOKS: Yes, and there's one other thing I need to say: It's not a complete package until you add energy, water, trace contaminants, and radioactivity.

PORTER: And landslides. You had a seminar here in the wake of Bluebird Canyon sliding down in Orange County—the first time [1978], rather than the second time in the last decade or so.

BROOKS: Yes, that's right. We established a big project, under my direction, about sediment balances. We're trying to trap sediments, yet the beaches are eroding because sediments aren't getting to the shoreline. We still haven't solved that problem.

We tackled a whole lot of things. For example, people were agitated about discharging cooling water [from Diablo Canyon nuclear power plant] into the ocean.

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[5] Glen Rowan Cass, "Methods for sulfate air quality management with applications to Los Angeles," Caltech PhD dissertation, 1978.

They said, "It's having a big effect on the larvae. We should stop that right away and use cooling towers." And we said that that would result in tremendous air pollution along the shoreline, because the cooling towers put out chemicals. You have to use de-chlorinating agents, and you also use a huge amount of fresh-water supply, and you lose 9 percent of the efficiency of the power plant. And I said, "You haven't proved to me what the harm is in the ocean, because what do you think kills the larvae all the time? The fish! Fish eat the larvae.

PORTER: Having grown up in Florida, I know that the thermal outfalls from power plants in the winter attract manatees, because in parts of the Atlantic and Gulf coasts, the water temperature drops, and they prefer to congregate near the outfalls.

BROOKS: Was that anticipated when they put the outfalls there?

PORTER: I don't believe so. That was probably an unexpected benefit—providing a habitat for endangered species during cold snaps.

BROOKS: Anyway, in EQL we tried to have collaborations outside the campus when it was appropriate, like Jim Krier from UCLA for law, and U.S. Geological Survey staff. Sometimes we got professional people who were paid for and were not Caltech appointees but who came with the understanding that they had to be qualified in a certain way and had to leave after five years. And we had an open publication policy, but obviously the writers and the investigators own the publication and the results until they're released to the public. I think that's Caltech policy, isn't it?

PORTER: I believe so—at least for faculty.

BROOKS: We didn't care if someone came around and said, "Give me a little tour of what you're doing now." For example, when we did cooling-water discharge model studies in the Keck lab, the condition I imposed was that we wouldn't do it in secret.

For example, if the water-control board said, “We want to see what your results are before you tell anybody else,” I would say, “No. You can come and see what we’re doing, and we’ll welcome your suggestions.” And people from different power companies did come, and that was fine. We had foreigners come to visit. Let me put it this way: We couldn’t let people come and stay with us for a couple of weeks—that wasn’t the idea. The idea was, you could have a reasonable site visit but not interfere with our work, otherwise we’d be spending all our time talking to visitors.

I want to clarify the difference between the EES option and EQL. EES didn’t have the power to make research-fellow appointments; we had to go through a division. EQL had more opportunities for outreach and also for fund-raising. They could say that they covered various issues relating to energy, air pollution, and so on—and did some studies that crossed divisional lines. That would be much more appealing to a donor, because it showed they were comprehensive and straightforward and open. There wasn’t quite enough of that in the rigid division system.

PORTER: The barriers between divisions seem to have diminished greatly.

BROOKS: Yes, and I think EQL helped to do that.

I don’t know if I made it clear that as director of an extradivisional organization I reported to the vice provost, so Neal [Cornelius J.] Pings was my contact with the Caltech administration. And sometimes the provost, Jack [John D.] Roberts, would want to talk to me, particularly about funding. And I would sometimes work on them to give us more of our overhead back. I’d say, “Well, we’re not supposed to pay for bookkeeping ourselves, that’s the institute’s overhead,” and there were other things like that. Roberts was a little bit fussy about that but, so I did have to do some bargaining.

We also organized conferences. In 1977, we had a conference on water issues in the Western United States, and we discussed all kinds of issues. Some people in those days would say, “Oh, if we need more water in California, we’ll just go to Idaho and pipe it down.” [Laughter] Our featured speaker at the end of the conference was Governor [Edmund G.] Brown [Jr.]; one of the things he said is that small is better. At another conference we held, at Scripps Institution of Oceanography, Jim Morgan and I invited all the wastewater people, the ocean-discharge people, and all the people at Scripps who were concerned about coastal-water quality, and they all came together and learned a lot from each other. Many of those people had never met each other before and didn't even know Scripps was doing this kind of research and tracking certain contaminants.

We had a conference at Lake Arrowhead for the policymakers, both on the wastewater side and the oceanography side. Jim Morgan presented a paper that was very interesting. Some people say copper is a bad pollutant in the ocean. He said, "OK, let's look at what the *natural* copper concentration is in Southern California coastal waters." It turns out that the discharge of copper is not a big problem, because there's a lot more there already. It's very informative to look at what the ocean already has in it, before you get too excited about some element in wastewater.

One microbiologist at the conference, a marine biologist, talked about how terrible it was to put all that pollution in the ocean, and I said, "Well, you heard me discuss how we treat the water and remove some things, and we use the ocean to help us with the rest of it. If we didn't put the wastewater in the ocean, where would you like to put the wastewater for 10 million people? Would you have an idea of where it should go?" He said rather quickly, "I guess I'd do just what you're doing." [Laughter] Environmentalists have that trouble sometimes—they think we have to stop doing this terrible thing regardless of the cost and whether or not it makes sense. So I tried to bring sense to the environmental community. I wrote a short paper back in the early '70s—I don't think I ever gave it to you—called "Environmental Escalation." It cautioned environmentalists to be sure that the environmental effects of what they were proposing wouldn't be far worse than what was currently being done.

PORTER: This may be a great place to end, and we'll transition to talk about your consulting work, among other things, in the next session.

BROOKS: OK, that sounds fine.

**[Tape ends]**

**NORMAN H. BROOKS**

**SESSION 3**

**June 18, 2018**

PORTER: Good morning. Last time, we covered most of your academic professorial career at Caltech. I was hoping that this time we could talk about the broader world outside Caltech—the outreach, your membership in the National Academy of Engineering, the National Academy of Sciences, and some of the major environmental, and engineering design work you've done over the years.

BROOKS: OK. Well, Caltech has an enlightened policy of allowing professors to spend one day per week, on average, on external work. The arrangement is that you're doing it under your own name, not leaning on Caltech's name. I would say that the work I did over the years on external jobs, most notably related to ocean outfalls—disposal of sewage effluent into the ocean—contributed significantly to my knowledge of engineering and was also useful to my teaching, in that I could talk to students about the real world of engineering as I saw it from going to these other places. It benefited me personally, but it also benefited Caltech.

PORTER: The consulting work informed the teaching.

BROOKS: Yes, that's right, and also the teaching and research informed the consulting work. There was quite a bit of consulting work that was unrelated to the laboratory work, but a lot of the consulting issues that came up became research projects in the laboratory. When those particular jobs were outside the usual consultation in somebody's office or in the field, a separate contract would be made with the hydraulics laboratory, which would then take care of bigger pieces of my time and also provide access to the Keck infrastructure. And we also had a policy that any laboratory work we might do in connection with consulting would not be closed; it would be open—full visibility. We did some laboratory studies on cooling-water dispersal from the San Onofre nuclear plant before it was built and before the design was finally settled. The question was, "Are you doing this for Edison?" I said, "No, we're doing it in the public interest." And that actually helped our credibility, because it meant we weren't doing something behind closed doors that the regulatory people didn't know about. So both sides appreciated the opportunity to observe us making these studies. On the other hand, we didn't give out the results of studies before we were finished. In other words, if somebody wanted to visit the laboratory, we were happy to show them the apparatus, how we did experiments, some sample results, but we never gave them a preview of the results. It wasn't that we were trying to restrain leakage of what we were doing; it was just because we didn't want the discussion to confuse things.

OK, now I'll go back: How did I get into this consulting business? As I mentioned earlier, I got into the ocean-discharge business because Dr. Vanoni, my advisor, was gone for the summer and I didn't feel I could effectively do my lab work at Caltech, and so I was hired, with the recommendation of Jack McKee, to work for the summer for the Los Angeles County Sanitation Districts. This was the summer of '52. The attitude was that the ocean is the place where you dump the effluent of the treatment plant, and what happens after that is that it's supposed to be "absorbed," quote-unquote, or disappear. There was no science beyond the end of the outfall pipe. My conclusions from that original summer of studies was that it makes a lot of difference how you introduce the effluent. If you use a lot of small jets, you get much more dilution and much more dispersal, instead of putting out one big lump and expecting it to get mixed, which is very inefficient. Later I did some work on thermal discharges into the ocean from power plants, making use of the same technology. We positioned the jets along a line that went straight out from shore, and on the end of the line—say, the last thousand feet—we'd have these jets coming out at an angle to the offshore alignment. This created a significant momentum into the ocean circulation, so that we actually changed the currents in the ocean. Momentum is the trick, because energy is dissipated but momentum is conserved; we were feeding a lot of momentum into the current, to push the discharge offshore, OK?

My consulting work in general had to do with using the ocean as a resource to help manage residuals, not just as a drop-off. That way could potentially save hundreds of millions of dollars of treatment costs and the associated energy and materials and labor costs.

I greatly enjoyed the opportunity to be involved with public infrastructure. It satisfied my inborn desire to do things that are useful to society—a public service. The Los Angeles County Sanitation Districts put me on a retainer for any kind of hydraulic problems that were bothering them, so I got involved with pump stations and things like that, too.

I think I'm a good observer of what's going on and what people are trying to do. For example, when I consulted in Athens, I asked them to introduce me to their oceanographers, and they said, "Oh, we don't talk to them." So I said, "Well, tomorrow we'll go meet them." I pushed the people who were in charge of these things to be much more aware of the oceanographic world. It turned out the oceanographers were doing things relating to the wastewater and sewage disposal problem, but they weren't talking to the dischargers, either—they'd say, "Well, they're just the engineers."

PORTER: Engineering and science need to work in concert.

BROOKS: That's right. So you can see how my consulting experience led to thinking about what needed doing at Caltech. First of all, let me say that as I became an expert, the news traveled. So when major projects came up, I inevitably heard from the engineers from firms who were competing to get the work. I wouldn't sign up with any one firm, because I wanted to be available to whoever got the job. By that time, my research was directed toward outfalls. What did I do that was so unusual? Well, it was just a workmanlike approach. You have to know what the currents are like at the site, you have to have an engineering expertise to design the jets and calculate the behavior of a buoyant jet in a stratified ocean environment. What you find is that if you go out to water that's deep enough and cold enough, in high-enough dilution—typically on the order of 100 or 200 to 1—you can affect the density of the mixture in such a way that it doesn't rise to the surface.

PORTER: Taking advantage of the thermocline to trap it.

BROOKS: That's right, to trap it. And that's exactly what happens in lakes; there is temperature stratification in the summertime, so the vertical mixing is impeded. I spent a year [1984-85] in Switzerland at the ETH, in Zurich, where I worked with one of the scientists on developing a computer model that would work for bubbling. If you bubble enough air into the bottom part of a lake, which is anoxic, the bottom water becomes buoyant. And also you can clamp down on the farmers, to keep them from spreading fertilizer in the springtime, when the ground is bare, because it will all wash down into the lake—

PORTER: You're talking about nitrification?

BROOKS: Nitrification, that's right. You can see that the basic fluid mechanics of stratified flow in many ways affects our environment—even with regard to smog. A lot of people say, "Let's just blow the smog away." I say, "No, the problem is too big. You can't recirculate that much." I developed a sense of what's doable and what isn't doable, because of having worked out these various problems earlier.

So, the initial discharge mechanics, that's one problem. After that, it's what happens to the sewage field after it rises in a cloud to some intermediate depth—or even up to the surface. Then you have to know about the ocean currents—the circulation off Southern California, for example, is coming from the north, mostly. And then you have to know something about bioaccumulation of toxic materials; if they're not diluted, they can re-concentrate. You have to talk to the biologists about what kinds of reactions occur. Most of the problem with regard to sewage effluent is knowing the BOD, the biochemical oxygen demand.

My major projects in California were San Diego, Orange County, Los Angeles County Sanitation Districts, Los Angeles, San Francisco, and then beyond California on the West Coast, Seattle, Vancouver, British Columbia, and then—

PORTER: And a huge project in Boston, toward the end of your career.

BROOKS: Yes, I'll come to that. On the East Coast: Suffolk County on Long Island and the southern coast of Long Island. In Europe, I did a major project in Athens. After Greece, I worked on projects in Istanbul, Izmir, and Alexandria, Egypt. Moving farther east, Taipei and Formosa. Sydney, Australia—I'll come back to that. Sydney and Boston were the biggest ones. In all those places, I emphasized that as a consultant you have to be observant and aware of all the relevant information. You have to go and see a lot of things with your own eyes, and you have to talk to people.

I want to slip in one anecdote that so amused me: I went to Taipei, and they showed me the maps, and I said, "This looks like a very extensive beach here. Is this where you have to watch out for coliform counts, if you put the outfall out from this area?" And they said, "Oh, no, because the Navy and the Army have prohibited swimming there. It's not a swimming beach." You can probably guess what my immediate reaction was: "I'd like to go see this beach." When we got there—I think it was on a weekend—there were thousands of bathers and a tower for lifeguards, and music broadcasting from it. The engineers were totally flabbergasted.

PORTER: A broad sandy beach is going to attract people around the world.

BROOKS: Yes, that's right. Anyway, I want to talk a little bit more about the regulators, and the chemists and other scientists, and the applied engineers who were designing the outfalls. And what about the oceanographers at a place like Scripps? How much do they pay attention to what the agencies are trying to do? You can probably guess. Jim Morgan and I had a conference at Scripps—I think I mentioned this. He and I thought it would be interesting to introduce people to what metals and hazardous stuff were already in the ocean before they got too excited about copper discharge, say. You'd better ask, "How much is already there?" and "If you dilute the wastewater by 100 to 1, is that a problem?"

PORTER: Right. Are you moving the needle or not?

BROOKS: That's right. This was quite revealing to the environmentalists at the conference. Sometimes, with environmentalists, the attitude is that the ocean is so pristine that we shouldn't be discharging any wastewater at all. Bacteria are part of the wastewater. But if you put the outfall miles offshore—for the city of Los Angeles, it's five miles offshore—OK, then—

PORTER: —how much actually gets back to the beach.

BROOKS: And how much time has elapsed before it gets there? What's the die-off rate? So you do all those things, the probabilities and statistics and which beaches are affected on which days—not all the sewage is going to all the beaches all the time. In other words, you have all this bacteria in the discharge, but how much of it actually will make someone sick? I needed to learn more about this from the oceanographers.

I want to finish up on outfalls and talk about Sydney and Boston. Sydney has some wonderful beaches, and they have a major outfall in the north, at Manly Beach, and one to the south, at a place called Malabar. This was in the mid-1980s. They wanted to build a tunnel for the outfall. They didn't want to put pipes out into the ocean, because the wave effects are so severe. In Sydney, 20-foot waves are coming in throughout the year. You can't just put the pipe on the seafloor and build a subsurface jetty to protect the pipe.

PORTER: So the wave zone is big and powerful.

BROOKS: And they had some good engineers there, who had been studying what I'd been doing over the years and applying it and doing reasonable things. In fact, I was learning from them. I walked into some of those tunnels under the ocean. They weren't that big, maybe 8 to 10 feet in diameter—this was during the construction. I went to Australia probably half a dozen times between 1983 and 1989, at different stages in the construction. They had an international committee looking at what they were doing in the various areas, and I was part of that international committee. I'd go there and I'd sit down at the desk and work out some engineering solutions.

PORTER: Would they have to start tunneling into rock significantly inland from the beach?

BROOKS: No, just near the beach. Anyway, the only way to get into the tunnel was down a gradual incline. Maybe it goes down at a 10-percent grade, so that the vehicles removing the soil can be pulled out on a track, probably by a winch, up to the surface. That's how we pedestrians who wanted to look inside got in; they gave us a ride down on the trolley to the bottom, and we could walk along.

PORTER: Would they then line the tunnel with concrete pipe, or would the rock wall be sufficient?

BROOKS: They had to line it. I think they probably did it in segments, but I don't remember exactly. When you get to the end of this tunnel—it's like 10,000 feet long—how do you get the discharge up to the sea floor? They had worked it out in a way which was quite intriguing to me. They used lasers to locate exactly where the end of the tunnel was to be, and there they had maybe some fifty risers, spread out over a couple thousand feet at the end of the tunnel. They drilled the risers through the rock at carefully determined locations. They did a very clever thing: They didn't just tap into the tunnel. No, they did an offset of about fifty feet, and they had a small boring operation, with a tube maybe two-and-a-half feet going from the tunnel to the riser. They filled the riser with dyed fluid, so when they went out there to find it, they could tell when they punctured the riser. So there was the main line, and the risers were there, and then they developed little tunnels, crosswise, as the feeder—the hydraulic link that lets the wastewater go from the main tunnel into the risers. It goes up the risers and has enough momentum to push up, and at the top was kind of a dome, with movable jets coming out in a fan shape.

PORTER: A lot of surveying precision to hit your targets.

BROOKS: Yes. Then the issue became, "How do you make sure the sewage is going out and the seawater isn't going in?" Particularly if you have these risers at different elevations along the seabed. How can you keep the seawater from pouring into one and the effluent coming out others? OK, so you had to purge the seawater. Also, when in operation, how do you maintain things so the seawater doesn't get back in? This is the problem I worked on with them. If you have enough dissipation ahead in the jets coming out of the top, it builds up the pressure inside the risers so the seawater can't go back through the nozzles. When the wastewater is flowing, the nozzles are creating a block to reverse flow. So what you have to do is make small-enough nozzles, and open only enough of them— Like at the beginning, you might put in 400 of these nozzles but you may want to open up only 250 for a while. I worked extensively on reviewing that kind of work, with the nozzles.

One interesting thing was, they said, "Well, we have a lab in England," and I said to them, "No, you have to do the model studies in Sydney. This is going to be your project. You ought to know what you're doing, and you have to have people available to look at it. I know a professor at the University of New South Wales, in Manly Vale, who does this kind of density-stratified research"—all these flows are called "density-stratified," meaning you've got more than one density fluid, and you have to know how to manage the flow of both of them. So I prevailed, and the professor did a very nice set of studies to find out the size of the ports and the number of ports. And when it started, it all worked fine.

Anyway, the next chapter, quick chapter, is Boston. What's the longest outflow I ever worked on? Boston—49,000 feet, a little over nine miles. Some of the engineers were worried about long pipes. I said, "I'm telling you what needs to be done," and actually the technology already existed, in the oil-pipeline industry, to do deep-water construction in different sizes, and so on. We had to deal with the state requirements and the Metropolitan District Commission of Massachusetts, which is a regional agency. So they had these rules, and they were working under a legal decree. There had been extensive pollution in Boston Harbor for years and years—huge pollution—and they had various rules they had to meet to satisfy the legal and judicial requirements. So I figured out what was needed to get out to deep-enough water, far enough from shore, so the pollution wouldn't be coming back into Boston Harbor. The engineers had decided to propose a three-mile rather than a nine-mile outfall and present it to a public-information meeting, and I told them, "You'll never sell this. It's too short!" They had some smart engineers who did stratified flow at MIT. It went all the way up to the point where I spoke to the president of the engineering firm that was doing the design work, and I said, "Do you want to follow the rules, or do you want to solve the problem? Your company's reputation depends on your solving the problem, not just following the rules if the rules are inadequate." That was a shocking thing for me to say, and they ended up checking with some environmental people, and they realized. . . .

As in Sydney, this had to be a tunnel outfall, because Massachusetts Bay had a lot of moraines from the recent glacial periods. And there was also the wave environment, because of hurricanes coming through occasionally. So they decided they had to have a tunnel. Then there were all these questions: How big should the diameter of the tunnel be? How do you get the discharge into the tunnel? How do you get it out of the tunnel and into the ocean to get the right diffusion? Well, the answer of how to get it out of the tunnel was a lot like Sydney. I took the technology I had learned in Sydney and applied it in Boston. They actually contacted Sydney and hired some of the engineers—one or two of them, I think—who worked on that system to come work in Boston for a while.

I greatly enjoyed doing all this consulting work, because it informed me and helped stimulate my research and my own field. Before we leave outfalls, I'll tell you a little bit about thermal cooling pipes.

PORTER: OK.

BROOKS: I think I mentioned John List and Robert Koh, my close associates for many years. Robert Koh was a senior research fellow—very outstanding. John List was one of my PhD students in the 1960s and stayed on at Caltech eventually becoming a professor of environmental engineering science. The three of us worked on the design of the cooling system for the San Onofre nuclear power plant. We came up with a cooling system, but the Atomic Energy Commission wouldn't approve the design. They said, "Our models show that it would be raising the temperature by four degrees more than is allowed in the AEC permit." So John List and Bob Koh made a few supplementary experiments in the laboratory, and they did some analysis of what the AEC didn't take into account. When my associates and I did model studies, we used all kinds of scaling equations and rules as to how to scale things up, and that's one of the things our laboratory was good at. So we designed it such that if the requirement was four degrees, we would scale it so we would be meeting that. The target was to get, after mixing, four degrees, with an absolute target of two-and-a-half degrees.

PORTER: Within how large a field?

BROOKS: Oh, the laboratory field was probably twenty feet by twenty-five feet.

PORTER: But in the end product, there's a four-degree target, and you're getting it down to two-and-a-half, but within what distance of the discharge does the temperature drop to that?

BROOKS: Almost immediately it's achieved by the jet mixing. The water is being pushed offshore to get more mixing water up to the jets. I can't remember offhand what the scale was and whether we may not have got all the discharge. Anyway, the fact that I put a margin of error in there was finally convincing to the AEC. They said, "Well, suppose the model isn't right?" We said, "OK, but we have allowed for that." We had very sensitive thermistors, a field of them, and the computer reads all that, so you can actually map the field and do the proper scaling. And when the plant was opened, conclusion: "It worked!" [Laughter]

PORTER: Problem solved.

BROOKS: Problem solved. Of course that didn't solve the other problems San Onofre had, and also for those people who were predicting dire consequences: " Well, the heat's going to do this and this." Actually, the heat was a benefit, as you mentioned the other day. Warm water in some places can stimulate the environment rather than damage it.

I want to address some more things here. The course I taught on hydrologic transport processes: I did not teach it as a manual for doing a particular kind of project but rather to teach the fundamentals, the tools we need to do all kinds of projects, and scaling rules. I think I mentioned that I found that the students weren't that competent in statistics. They couldn't tell you right off the bat what the standard deviation means or what the autocorrelations are—and you use statistics for all kinds of things in hydrology. So we spent a few weeks on using statistics and being able to be conversant. There were other fundamentals, to do with density-stratified flow, groundwater flow, how turbulence is affecting what you're doing, how seawater intrudes into aquifers.

After we got through with that, we did quick work on diffusion theory, the basic theory of heat conduction, and the usable differential equations for figuring out heat problems. I got them to the point where I could say, "You don't have to be doing all the Laplace transforms and all this. You've got certain kinds of problems, like heat conductors. There's a certain Laplace equation, different ones have different kinds of equations, and you know certain basic things, so if you know the diffusion coefficient and you know the normal distribution and the parameters of it, you can figure out on the back of an envelope for a certain diffusion coefficient and certain sizes." You're not actually doing the math every time, you can actually just know what you're doing.

So, for the rest of the class, we did diffusion exercises on rivers—longitudinal dispersion. That's where you have the turbulent mixing, the vertical moving of the pollutant into a concentration profile of a depth and what that means. One of our students did an experiment in one of the suburbs of Seattle; he put a big dye drop in one of the rivers and then measured how it spread out in the next five miles. And knowing the velocity distribution, he was able to confirm that his laboratory analysis, with the proper scaling, was able to predict that kind of behavior. So we opened up the door on a lot of previously unknown territory, about the dispersion in natural rivers of things that get spilled into them or are discharged on purpose. We now have a much better idea about where a spill is going to end up, and how it's going to be diffused, both by steady flows and unsteady flows. This was my class: It dealt with a whole network of tools for different kinds of problems. I really liked that course. I didn't write a textbook, because I didn't want to be fixed about the kinds of phenomenon you're dealing with. I wanted the students to learn that if they weren't familiar with a certain kind of mixing or turbulence phenomenon, they should look into it and not be constrained by what's in a book.

I did do a book with Robert Koh, John List, Hugo Fischer, and Jörg Imberger. It was called, *Mixing in Inland and Coastal Waters* [Academic Press, 1979]. It's not about groundwater, it's about rivers, coastlines, freshwater lakes, and the kinds of things that affect them, like stratification. Hugo Fischer was the principal author; I probably was the one who encouraged it. In fact, one of the rewards of being a teacher is having students like Hugo Fischer. He came to Caltech initially as an undergraduate. He got a Master's degree [1963] and went off and did some other things, and I persuaded him to come back and get a PhD [1966]. And his mother, at his graduation, made a remarkable comment to me: She said, "Thank you for persuading Hugo to go back and get a PhD." That's a very rewarding thing for a teacher to hear. My first student, John Fisher Kennedy, also finished getting a Master's degree [1956], and I said, "Why don't you come back and get a PhD?" He said, oh, no, I gotta do this and this and this. He came from New Mexico. He was very much of a can-do kind of person. I knew he could do a good job. He thought about it, and I wrote to him and persuaded him some more, and he became my first PhD student. So as a young professor in the 1950s, you had to see if you could catch some of these students. For example, when I was getting a PhD in civil engineering, I think there was just one other person that year in civil engineering who got a PhD. There wasn't a whole roster in those days; this was pre-environment, pre-digital, pre-emails, all these useful things.

One other thing I want to mention about my teaching: After the students had been here one semester or so, I gave them oral exams as a final exam. That sort of shocked them. I said to them, "When you go work somewhere, the boss can say, 'Explain to me what you've been doing on this problem, and I want you to tell me in five or ten minutes.'" As an example of that, I remember testifying at a hearing for the Clean Water Act, and Senator Edmund Muskie was the chairman of the committee. He said a wonderful thing that set me up. He said, "I go to all these hearings, and people talk about all the advantages of deep-water discharges. Can you explain to me how all that works? What does it mean to be some distance from shore, why does it make the pollution go away? It seems like a wish." And so I explained it to him. I think my testimony before that committee is probably here in the library somewhere.

PORTER: I believe it is.

BROOKS: But one of the things I impressed on him was the importance of not mandating secondary treatment, which is what the committee wanted to do, because there were going to be a lot of places—with engineers like me and with favorable ocean conditions like the West Coast—that are really quite appropriate for the kinds of outfalls I was talking about. I think finally in the bill there was a procedure for getting a waiver from secondary treatment in places where the size of the discharge and the oceanographic and other conditions were such that it would be a waste of money to do secondary treatment. By that time, we had some examples working very well, just on primary treatment.

PORTER: Technology changes, and the environmental conditions in different places vary.

BROOKS: Oh, yes, there are great differences. There's no sense in mandating doing twice as much as you need to do, because it's just a waste of the country's resources. I told them, "You have an obligation to be efficient and maintain costs that are in concert with the benefits. You can't just assume that you have to have a certain benefit regardless of the cost."

A couple other quick things: The National Academy of Engineering was formed in the 1960s, similar to the National Academy of Sciences in concept, for nominating distinguished people. I was elected in 1973. The academy was only about ten years old at the time, so probably they weren't looking very closely. This led to my being on a number of different committees. For example, I was appointed to the environmental studies board of the National Research Council. They mandate studies and publish reports of their own—the idea being to provide the academy a place where what you're trying to do for the environment gets some high-level scrutiny so you're not rushing off doing all kinds of stuff that's not the right thing to do.

PORTER: The books that come out of the National Academy's press are excellent material.

BROOKS: Yes, that's right. One of the ones I worked on—I've forgotten the title, but it's about taking care of environmental problems of a coastline with urban discharges. [*Managing Wastewater in Coastal Urban Areas*: National Academy Press, 1993—ed.] It might not have my name on it, it's probably got the committee's name on it. I had some difficulties with the staff on that. The committee was made up of a variety of scientists—economists and political scientists and so on and various engineers. For instance, I wanted the book to say that reducing the BOD doesn't necessarily have to be part of the treatment, for the right kind of place. You have to find out what pollutants are doing the damage. The staff wanted a more standard legal framework. The NRC shouldn't be writing a book of regulations, they should be emphasizing the science. So after a little bit of struggle—and actually a revolt—they agreed with me that what we should be trying to look at is the scientific processes and how technology meets the challenges in different places. I was in charge, but there were different subjects. One of the major sections in the book was environmental processes, and I headed that chapter. Another NRC book was on flood reports, from 1978 and 1980. Then there was a book produced by NOAA, not so well known, but it's about coastal processes, and that was one that EQL agreed to provide several of the chapters for. I have a black two-volume set; it probably was in the library at one time.

OK, then something else I want to mention: I was a member of Caltech's centennial symposium committee, in 1991—"Visions of a Sustainable World." The committee had a number of Caltech faculty, and Murray Gell-Mann [Millikan Professor of Theoretical Physics, emeritus; d. 2019] was on the committee. I'm not sure if he was the chairman, but he was very influential. This was somewhat in the style of *The Next Hundred Years*. [*The Next Hundred Years: A Discussion Prepared for Leaders of American Industry*, by Harrison Brown, James Bonner, and John Weir: Viking Press, 1957—ed.] It was a series of lectures by prominent people—some of my colleagues on the committee. We captured one day out of the three-day conference, saying, "Look, you keep talking about 'The world this' and 'The nation this,' and I want to talk for a day about the visions for a sustainable California. After all, we keep telling ourselves we're one of the top ten economies in the world. And this is Caltech, we're in California." So they agreed to that, and I took the initiative and organized the papers and speakers, and also I asked some of the speakers to write their ideas down for a special issue of [the Caltech magazine] *Engineering and Science*. I felt pretty good about that, because one of the highlights was Glen Cass; he's the one who was really good at modeling air pollution. He'd written many, many papers. As a result of the discussion, he made a model run of the situation in the Los Angeles area by removing all the inputs from car exhaust. In other words, what would it be like if there were no automobiles? Leaving all the refineries and factories and everything else in. And it turned out that automobiles were accounting for 80 percent of the pollution. Up until then, some of the people in the car business were claiming that cars weren't the problem—it was the backyard incinerators and the refineries that were the problem.

PORTER: California is allowed currently to set their own air-pollution requirements for automobiles, separate from the EPA standards.

BROOKS: Yes.

PORTER: And a number of states in New England have chosen to adopt the California standards along the way.

BROOKS: Yes.

PORTER: Going back to your original research on stream flow: I understand that you would take students up into the canyons here in the San Gabriels to observe the storm-level stream flows.

BROOKS: Yes. As you might expect, some were enthusiastic about it, some weren't. [Laughter] But anyway, as far as local trips, some of the trips were just an hour, observing how stream runoff behaves. I got into the habit of taking field trips, so during the construction of Glen Canyon Dam—which I opposed, with letters to Congress and so on—I took the students there so they could see what the canyon looked like before the dam went up. The highlight of that trip was, we stayed in the workers' lodgings, because there wasn't anything else around there. We arranged it with the Bureau of Reclamation, and we sat at tables in the big dining room, often with some of the construction workers. That was interesting. One time we sat with one of the construction supervisors; he was a tough, know-it-all kind of a guy. I told him that we were on a field trip to learn about how this work was done. He says, "Oh, don't listen to those damn professors, just come out here and see how we do it. [Laughter] And a student said, "Hey, he *is* the professor!" [Laughter] I was probably about twenty-eight years old then. I was taking these students on these trips when I was pretty young.

It was in the Arroyo Seco that I met Ron Scott. That was during a heavy rainstorm. I went up there to see who was watching at the bridge just near the water intake and what else was happening. And in the pouring rain who should I meet but Professor Ronald Scott! He was an enthusiastic viewer of landslides. We used to make a joke: He gets the landslides dumped into the streams, and I get the stuff transported downstream. So there we were. Neither of us probably should have been out there by ourselves. None of our students were available. Maybe it was the weekend, but I wouldn't have taken them up there anyway, too much risk. But anyway, it was very revealing that another professor was also of the same frame of mind. You have to see these things for yourself; you can't just read about it in a book.

Just a quick word about sabbaticals. I took five sabbaticals altogether during my forty years. One was to Bangkok, where they were setting up the SEATO Graduate School of Engineering [1959-1960]. I was one of the people there to teach hydraulic engineering, and I was supposed to be the specialist on sediment transport. But in developing my lectures, I included a lot of ordinary engineering information, too, such as how to do certain simple statistics, how to do calculations, how to use a slide rule—there were no computers. And I used to go to lunch with the students. They would get fried rice for 15 cents. They couldn't understand why I was so heavy when we all went to the lab to weigh in. I wanted to see how much I weighed—whether I was gaining or losing weight after about five months in Thailand. I couldn't believe how much I weighed.

They gave me a shop-made office chair—a wooden office chair. It looked very nice, but the first time I sat in it, the legs splayed out like this, and I thought, "We're done!" [Laughter]

So anyway, it was very challenging. If you're interested, the article I wrote about that period, "The Challenge of Technical Assistance," was in *Engineering and Science*. [Vol. XXIV, No. 1, pp. 13-17, October 1960]. To deliver lasting assistance, it's more a matter of sending good people, rather than sending crates and crates of equipment. I was always an active observer of the bigger world around us—and I wanted to get students away from thinking everything depends on a computer program or a textbook.

I was trying to do too many different things—not giving up one thing when I took on something else, like when I became the director of EQL. I didn't want to give up my teaching—maybe some basic courses, but I still wanted to have my PhD students. I didn't want to give up my foothold in civil engineering. I also served on various kinds of administrative or faculty committees.

Caltech was a very challenging and satisfying experience for me, but it was, obviously, disheartening when the administration decided not to continue the Keck Laboratory of Hydraulics and Water Resources. We named it hydraulics and water resources to emphasize that we weren't just a laboratory, we were a laboratory associated with a field of work. It was also disheartening to see the Environmental Engineering and Science program shifted to geology, which was a valid reaction, I guess, to changing interests and changing priorities. It shifted to practically all science and very little engineering. I'm not trying to comment on how things are now, because I wasn't present, but I'll just say, at the time it was disheartening to see it move. But I recognize that universities evolve and go in different directions. I arrived after World War II on an upswing and got caught in the downswing. I do want to mention the opportunity that the Caltech Archives provided me to try to preserve many of the documents of the hydraulics laboratory and EQL documents in digital form. And many, many environmental reports, too. We've got hundreds of documents—I think probably over five hundred—that might otherwise have been lost in the shuffle. I have to acknowledge your own very diligent efforts to help in that process, and then of course my grandson, who volunteered to help move things out from Keck. Since my retirement I have had some health issues that have slowed me down, so I haven't had the same kind of energetic appetite for some of these activities. And I hope my former students and colleagues will forgive me if I haven't been responsive to their occasional letters or emails, because I just wasn't able to encompass that level of communication. So I thank you, George, and I thank my son Alec. He helped persuade me to do these interviews, and he helped me think about it and arrange for it. And as a final note, Frederika has been a very loyal and helpful mate and wife for even longer than I've been at Caltech, almost seventy years, and I'm very grateful to her for all the things she did that made it possible for me to travel and work and at the same time be a very active party in raising our family of three children.

And also my thanks to the people on the staff who worked with me, some of them for very long periods of time—in the Keck lab and civil engineering before that and also at EQL. There are too many to mention them all, but they were very helpful, and particularly I appreciated the staff who would tell me if I was getting off the track on what I was trying to do. I still have staff persons in Keck—in different fields, but they're still looking after my basic needs administratively. I still occupy an office, which has yet to be taken apart. Again, I'm grateful to Caltech and their ongoing assistance and contact with me. I never wanted to go work at any other university.

**[Tape ends]**