Zooplankton

TZMAX

55. TZMAX is the maximum ingestion rate for zooplankton (l/day). The zooplankton compartment includes the groups Cladocera, Copepoda, and Rotatoria which are classified as either herbivores or as carnivores.

56. Two types of feeding behavior exist: filter feeding and grasping feeding. Daphnia and some copepods are filter feeders. They collect particulate matter, including algae and detritus, by sieving lake water through the fine meshes of their filtering apparatus (Jorgensen 1975). Algae are swept into the feeding appendages to the mouth region where they are ingested as boluses containing many cells. Filter-feeding zooplankton make up the greater proportion of the zooplankton community and have been studied in greater detail.

57. The filtering rate per animal decreases as food concentration increases; above a critical concentration of food, the feeding rate is independent of food concentration.

58. Factors that influence food consumption by filter-feeding zooplankton include (a) animal density, size, sex, reproductive state, nutritional or physiological state as well as (b) the type, quality, concentration, and particle size of food. Other factors include water quality and temperature.

59. A second type of feeding behavior, raptorial or grasping feeding, is exhibited by most copepods and some cladocerans. They pursue prey and grasp large particles, including algae and detritus. Apparently, some copepods can switch feeding modes.

60. Several experiments have been able to demonstrate a maximum grazing rate allowing for long-term acclimation to food concentration above the incipient limiting level. Values for TZMAX range from 0.045 to 3.44 l/day.

61. Dissolved organic matter (DOM) is another potential source of food for zooplankters, although this feeding transfer is not modeled in CE-QUAL-Rl. values for maximum ingestion rates for zooplankton are given in Table 12.

Table 12

Maximum ingestion rates for zooplankton (l/day)

PREDATOR	VALUE	FOOD SOURCE	REFERENCE
Bosmina	0.01	detritus	Bogdan and McNaught 1975
Brachionus rubens	3.438	Chlorella vulgaris	Pilarska 1977
Cladocerans	0.15	detritus	Bogdan and McNaught 1975
Copepods	0.10	detritus	Bogdan and McNaught 1975
Daphnia	0.01	detritus	Bogdan and McNaught 1975
Daphnia magna	0.251	Saccharomyces cervisiae	McMahon and Rigler 1965
oapnnia magna	0.452	Tetrahymena pyriformis	McMahon and Rigler 1965
Daphnia magna	0.301	Chlorella vulgaris	McMahon and Rigler 1965
Daphnia magna	0.045	Escherichia coli	McMahon and Rigler 1965
Daphnia magna	0.760	Chiorelia vulgaris	Kersting and Van De Leeuw-Leeqwater 1976
Daphnia magna	0.350	Saccharomyces cerivisiae	Rigler 1961
Daphnia magna	1..	ChIarella vulgaris	Ryther 1954
Daphnia magna	2.2	Navicula pe11iculosa	Ryther 1954
Uaphnia magna	2.3	Scenedesmus quadricauda	Ryther 1954
Daphnia pulex	0.120	Chlorococcwn sp.	Monokov and Sorokin 1961
Daphnia rosea	0.900	Rhodotaru1a glutinis	Burns and Rigler 1967
Diaptomus	0.47	detritus	Bogdan and McNaught 1975
IN SITU EXPERIMENTS			
Heart Lake, Canada	0.801	Various	Haney 1973
Lake Vechten, The Netherlands	0.24	Various	Gulati 1978
Lake Krasnoye, USSR	1.20	various	Andronikova 1978

TZMORT

62. TZMORT is the maximum nonpredatory mortality rate for zooplankton (l/day). Nonpredatory mortality rate may be obtained by measuring total mortality and predatory mortality and subtracting to obtain the difference (a direct approach is to measure mortality rate and eliminate predators altogether). Nonpredatory mortality may be influenced by oxygen concentration, temperature, diet, age, and population density. Nonpredatory mortality rates are normally less than 1 percent per day. Values for maximum nonpredatory mortality rate are given in Table 13.

Table 13

Zooplankton mortality rates (l/day!

SPECIES	TZHORT	REFERENCE
Calanus helgolandicus	0.003-0.048	Paffenhoffer 1976
Calanus nelgolandicus	0.024	Mullin and Brooks 1970
Carnivorous zooplankton	0.002-0.013	Petipa et al. 1970
Ceriodaphnia reticulata	0.0016	Clark and Carter 1974
Copepod nauplii	0.006-0.017	Petipa et al. 1970
Daphnia galeata	0.017	Hall 1964
Daphnia pulex	0.012	Craddock 1976
Daphnia pulex	0.018-0.027	Frank et al. 1957
Daphnia retrocurva	0.001	Clark and Carter 1974
Daphnia rosea	0.001-0.007	Dodson 1972
Daphnia rosea	0.001	Clark and Carter 1974
Daphnia spp.	0.002	Wright 1965
Diaptomus clavipes	0.004-0.155	Gehrs and Robertson 1975
Diaphanosoma leuchtenbergiana	0.001	Clark and Carter 1974
Omnivorous zooplankton	0.010-0.013	Petipa et al. 1970
Paracalanus sp.	0.003-0.006	Petipa et al. 1970
Rhinca1anus nasutus	0.006-0.015	Mullin and Brooks 1970
Sirnocephalus serrulatus	0.003	Hall et al. 1970

ZEFFIC

63. ZEFFIC, the zooplankton assimilation efficiency (A/G) {dimensionless}, is the proportion of food consumed (G) to food assimilated (A), i.e., food actually absorbed from an individual's digestive system. The assimilation efficiency is used to modify consumption and to determine the quantity of energy entering an individual or population.

64. Of the factors affecting assimilation efficiency, the most significant is food type. For herbivores-detrivores, the range in ZEFFIC is wide because these animals often consume foods of varying energy content and digestibility. Among the carnivores, for which food type varies little, A/G ranges between 0.80 and 0.95. Values for zooplankton assimilation efficiency are given in Table 14.

Table 14

Zooplankton assimilation efficiency coefficients (dimensionless)

SPECIES	ZEFFIC	REFERENCE
Acartia c1ausi	0.66-0.73	Penchen'-Finenko 1977
Bosmina coregoni	0.09-0.77	Semenova 1914
Bosmina longirostris	0.32-0.31	Gute1'mackher 1977
ca1anus firmarchicus	0.45-0.96	Marshall and Orr 1956
Ca1amoecia 1ucase	0.63-0.67	Green 1975
Ceriodaphnia reticu1ata	0.106	Czeczuga & Bobiatynska-Ksok 1970
ceriodaphnia reticulata	0.47-0.73	Czeczuga , Bobiatynska-Ksok 1970
Cyclops strennus	0.50	Schindler 1971
cyclops vicimus	0.80	Monakov 1972
Daphnia longispina	0.10-0.25	Monakov , Sorokin 1961
Daphnia longispina	0.42	Honakov 1972
Daphnia magna	0.60-0.84	Schindler 1968
Daphnia pulex	0.14-0.31	Richman 1958
Daphnia schodleri	0.60-0.90	Hayward , Gallup 1976
Daphnia sp.	0.08-0.25	Cohn 1958
Diaptomus graci10ides	0.81	Penchen'-Finenko 1977
Diaptomus graci10ides	0.45-0.50	K1ekowski & Shushkina 1966
Diaptomus sici10ides	0.40-0.83	Comita 1972
Diaptomus oregonensis	0.71	Richman 1964
Eurycercus 1ame11atic	0.07-0.32	Smirnov 1962
Ho1opedium gibberrum	0.10-0.47	Gute1'mackher 1977
Leptodora kindtii	0.40	Cummins et a1. 1969
Leptodora kindtii	0.87	Hi11bricht-I1kowska & Karabin 1970
Macrocyclops albidus	0.45-0.50	K1ekowski & Shushkina 1966
Mesocyc1ops a1bidus	0.20-0.75	K1ekowski & Shushkina 1966
Polyphemus pediculus	0.42	Monokov 1972
Sida crysta11ima	0.11-0.99	Monakov 1912
Simocephalus esplno5us	0.46	Sorokin 1969
Simocephalus vetulus	0.31-0.72	K1ekowski 1970
Simocephalus vetu1us	0.31-0.72	lvanova & K1ekowski 1912
10 herbivores	0.476	Comita 1972

PREFl, PREF2, PREF3

65. All zooplankters are selective feeders resulting from a cOmbination of (a) an organism's mechanical limitations in capturing and processing food items of varying size and configuation, (b) the chemical composition of the food items, and (c) feeding behavior. Food preference is demonstrated if an organism consumes a food item in a proportion different from the food item1s relative contribution to the total of all available foods in the environment. If all foods occur at the same concentration. then the preference factors equal the fractions of ingestion contributed by each food compartment. Seasonal abundance of phytoplankton, bacteria, and detritus may be the main factor determining the percent composition of these components in the diets of many zooplankters.

66. Filamentous bluegreen algae are generally not considered to be as assimilable as are other algal species. They are seldom found in the guts of zooplankton, because they either are not eaten or are actively rejected. Most species of green algae and diatoms are filtered at about the same rate and digested. However, it is not necessarily the taxonomic position of the alga that makes it suitable or unsuitable as food, but rather the attributes of each algal species such as size, shape, and toxicity.

67. Although ample evidence exists to show that detritus is consumed by zooplankton, no evidence exists to show that it is consumed preferentially; rather, detritus is ingested in proportion to its composition in the environment. When detritus is included as a food source in a grazing formulation, it should be given equal ranking with other suitable foods. It should be noted that bacteria that colonize detritus constitute an important source of protein in the diet.

68. Filter feeders discriminate among particles on the basis of size, shape, and texture. There are upper and lower limits to the sizes of particles that can be managed by zooplankton feeding appendages. Particles of 0.8 μ and larger can be retained; an upper limit is related to the size of the animal. Algae that clog the filtering appendages are rejected from them by a claw on the lower abdomen.

69. Raptorial feeders can sieze large prey and tear it apart before eating (Ambler and Frost 1974, Brandl and Fernando 1975), but there are limits to the size of prey they capture.

70. PREF1 is the preference factor of zooplankton for the ALGAE1 compartment, PREF2 is the preference factor of zooplankton for the ALGAE2 compartment. and PREF3 is the preference factor of zooplankton for the detritus compartment. The food preference factors are dimensionless; the total of the three factors must equal 1. Values for these preference factors are given in Table 15.

Table 15

Food preference factors of zooplankton (dimensionless)

PREDATOR	PREF	PREY	REFERENCE
Bosmina	0.33	nannoplankton	Bogdan and McNaught 1975
Bosmina	0.33	netplankton	Bogdan and McNaught 1975
Cladocerans	0.30	nannoplankton	Bogdan and McNaught 1975
Cladocerans	0.30	netplankton	Bogdan and McNaught 1975
Cladocerans	0.20	bluegreen algae	Bogdan and McNaught 1975
copepods	0.45	nannoplankton	Bogdan and McNaught 1975
copepods	0.15	netplankton	Bogdan and McNaught 1975
copepods	0.20	bluegreen algae	Bogdan and McNaught 1975
Daphnia	0.33	nannoplankton	Bodgan and McNaught 1975
Daphnia	0.17	netplankton	Bogdan and McNaught 1975
Diaptomus	0.40	nannoplankton	Bogdan and McNaught 1975
Diaptomus	0.17	netplankton	Bogdan and McNaught 1975

TZRESP

71. TZRESP is the maximum zooplankton respiration rate (l/day). Respiration is the sum of all physical and chemical processes by which organisms oxidize organic matter to produce energy. Respiration rates of aquatic invertebrates usually are estimated directly by monitoring oxygen consumption. By mUltiplying oxygen consumed times an oxycaloric coefficient {i.e., 4.83 cal/ml 02 (Winberg et al. 1934» and the energy-to-carbon relation for aquatic invertebrates *(i.e.,* 10.98 cal/mg C (Salonen et al. 1976», the amount of carbon metabolized can be determined and converted to biomass.

72. Conover (1960) has indicated that carnivores have higher respiration rates than herbivores. Values for maximum zooplankton respiration rates are given in Table 16.

Table 16

Zooplankton maximum respiration rates (1/day)

SPECIES	TZRESP	REFERENCE
Bosmina coregoni	0.170	Manuilova 1958
Bosmina longirostris	0.185	Sushchenya 1958
Ceriodaphnia reticulata	0.18-.50	Gophen 1976
Copepoda	0.075-.204	Bishop, 1968
Copepod adults	0.043-.131	Williams 1982
Copepod copepodites	0.054-.171	Williams 1982
Copepod nauplii	0.165-.695	Williams 1982
Copepod total	0.056-.183	Williams 1982
Daphnia ashland!!	0.447-.74	Duval and Geen 1976
Daphnia clavipes	0.117-.165	Comita 1968
Daphnia cuculata	0.161	Manui10va 1958
Daphnia galeata	0.13-.772	LaRow et al. 1975
Daphnia hyalina	*0.179*	B1azka 1966
Daphnia longispina	0.121-.135	Tezuka 1971
Daphnia longispina	0.16	Manuilova 1958
Daphnia longispina	0.146	Shushkina and Pecen' 1964
Daphnia magna	0.085-.175	Kersting and Van De Leeuw-Leegwater 1976
Daphnia magna	0.014	Sushchenya 1958
Daphnia oregonesis	0.194	Richman 1964
Daphnia pulex	0.582	Buikema 1972
Daphnia pulex	0.18-.19	Tezuka 1971
Daphnia septopus	0.008-.18	Comita 1968
Daphnia siciloides	0.006-.52	Comita 1968
Diaphanosoma brachyurum	0.272	Sushchenya 1958
Diaptomus kenai	0.272-.448	Duval and Geen 1976
Leptodora kindtii	0.471	Moshiri et al. 1969
Leptodora kindtii	0.125	Hillbricht-Ilkowska and Karabin 1970
Simocephalus vetulus	0.131	Sushchenya 1958
Simocephalus vetulus	*0.154*	Manuilova 1958
Simocephalus vetulus	0.096-.201	Ivanova and Klekowski 1972
Total zooplankton	0.063-.210	Williams 1982

ZS2P

73. ZS2P is the zooplankton half-saturation coefficient for grazing on algae and detritus (mg/L). It has been found that zooplankton exhibit reduced feeding rates at high food concentrations; the relationship between feeding rate and food concentration has been reported to be curvilinear bya number of investigators (Burns and Rigler 1967, Parsons et al. 1967, McQueen 1970, Frost 1972, Monakov 1972, Gaudy 1974, and Chisholm et al. 1975).

74. The most realistic calculation of zooplankton grazing rate is based on their rate of removal of biomass of food (Mullin 1963); therefore, it is important that investigators report results in terms of biovolume or biomass instead of cell number. The method most used to determine ingestion rate is to count prey in controls and experimental chambers after feeding zooplankton. Values for zooplankton HSC are given in Table 17.

Table 17

Zooplankton half-saturation coefficients (mg/L)

SPECIES	ZS2P	REFERENCE
Bosmina coregoni	4.0	Scavia and Eadie 1976
Daphnia magna	9.6-15.0	Scavia and Eadie 1976
Daphnia rosea	0.16	Scavia and Eadie 1976
Diaptomus oregonensis	1.6	Scavia and Eadie 1976

ZOOT1, ZOOT2, ZOOT3, ZOOT4

75. Values for zooplankton temperature coefficients are given in Table 18.

a. ZOOT1 is the lower temperature bound at which metabolism continues to occur. It is generally 0°C.

h. ZOOT2 is the lowest temperature at which processes are occurring near the maximum rate (0 C) •

c. ZOOT) is the upper temperature bounding the range of maximum rates (QC).

d. ZOOT4 is the upper lethal temperature (QC).

Table 18

Zooplankton temperature coefficients (DC)

SPECIES	ZOOT1	ZOOT2	ZOOT 3	ZOOT4	REFERENCE
Calamoecia lusasi	NA'	20	24	NA	Green 1975
Ceriodaphnia reticulata	NA	2.	27	NA	Gophen 1976
Daphnia galeata	NA	20	24	NA	Burns 1969
Daphnia longispina	NA	,•	18	NA	Nauwerck 1959
Daphnia magna	NA	24	2.	35	McMahon 1965
Daphnia magna	NA	25	NA	NA	Burns 1969
Daphnia middendorffiana	NA	24	25	NA	Kryutchkova and Kondratyuk 1966
Daphnia pulex	NA	20	24	NA	Burns 1969
Daphnia pulex	NA	20	24	NA	Geller 1975
Daphnia pulex	NA	NA	25	NA	Geller 1975
Daphnia rosea	NA	20	24	NA	Burns & Rigler 1967
Daphnia rosea	NA	14	15	NA	Kibby 1971
Daphnia schedleri	NA	20	22	NA	Burns 1969
Daphnia schedleri	NA	20	24	NA	Hayward & Gallup 1976
Diaptomus sp.	NA	1.	18	NA	Nauwerck 1959

* NA not available.

76. As with the phytoplankton, zooplankton are able to adapt to the ambient temperature with time. This is demonstrable throughout the different regions of the United States and at different times of the year. Zooplankton found in temperate regions of the United States are exposed to lower average temperatures throughout the year and consequently have lower temperature factors (i.e., ZOOT1, ZOOT2, ZOOT3, and ZOOT4) than those found in more southern regions. Again, these values are unavailable from the literature but have been estimated by Leidy and Ploskey (1980) based upon acclimation temperatures (Table 19).

Table 19

Acclimation temperature, upper and lower lethal temperature, and the temperature range for a constant maximum grazing rate for zooplankton exposed to rapid temperature stress (°C) (from Leidy and Ploskey 1980)

Accl. Temp.	ZOOT1	ZOOT2	ZOOT3	ZOOT4
5	0	5	6	25
10	0	10	12	30
15	2	15	18	33
20	5	20	24	33
25	7	25	30	34
29	10	29	34	34
30	10	30	34	34
31	12	31	34	34
34	15	34	34	34
35		lethal		

Table 20

~~Daily ration of benthic orga~~nisms (from Leidy and Ploskey 1980) Cl/day)

SPECIES	FOOD	RATION	REFERENCE
NEMATODA			
Aphelenchus avenae	fungal mycelia	0.26	Soyza 1973
Plectus palustris	Acinetobacter sp.	6.50	Duncan et al. 1974
MOLLUSCA			
Dreis.ena polymorpha	bacteria	0.01-.12	SOrokin 1966
Goniobala clavaeformis	aufwucks	*0.01-.24*	Malone and Nelson 1969
ARTHROPODA			
Hyalella &zteca	sediments	0.17-1.03	Hargrave 1970
Pontogammarus robustoides	Cladophora sp.	0.007-.98	Xititsyna 1975
Pontogammarus robustoides	Tubifex sp.	0.187-1.63	Xititsyna 1975
PODOCOPA			
Chaoborus flavicans	natural phyto-plankton population	0.036-.114	Kajak and Dusoqe 1970
Berpetocypris reptans	Spirogyra sp.	1.28	Yakovleva 1969
Herpetocypris reptans	Zygnema sp.	0.93	Yakov1eva 1969
Herpetocypris reptans	Mougeotia sp.	*0.93*	Yakovleva 1969
Herpetocypris reptans	Chironomus plwnosus	*0.66*	Yakovleva 1969
Herpetocypris reptans	Asellus aquaticus	*0.66*	Yakov1eva 1969
Herpetocypris reptans	fish fry	1.09	Yakovleva 1969
Procladius choreus	Chironomidae	0.007-.11	Kajak and DU60ge 1970
EPHEMEROPTERA			
Stenonema pulche11wn	Navicula minima	*0.234*	Trama 1972
PLECOPTERA			
Acroneuria califomica	Hydropsyche sp.	0.002-.087	Heiman and Knight 1975

Benthos

TBMAX

77. TBMAX is the maximum ingestion rate for benthos (l/day) and is measured at food densities above the incipient limiting food concentration. The food source for this compartment is organ1c sediment; its dominant members for most reservoir benthic communities are the aquatic oligochaetes and Chironomidae. Filter feeders, predators, deposit feeders, and surface grazers are all represented in most benthic communities.

78. Daily rations (an approximation of the daily grazing rate) of some benthic species compiled by Leidy and Ploskey (1980) are listed in Table 20. Other values for maximum ingestion rate are given in Table 21.

Table 21

Benthos maximum ingestion rates (l/day)

SPECIES	TBMAX	REFERENCE
Acroneuria californica	0.002- .09	Heiman and Knight 1975
Asellus aquaticus	0.25	Prus 1972
Carnivores	0.0282	Bigelow et al 1977
Chaoborus flavicans	0.036-.114	Kajak and Dusage 1970
Deposit feeder	0.111	Gordon 1966
Hyalella azteca	0.11-1.3	Hargrave 1970
Omnivores	0.043	Bigelow et al. 1977
Pontagamrnarus robustiodes	0.074-.98	Kititsyna 1975
Procladius choreus	0.07-.11	Kajak and Dusoge 1970
Selective deposit feeder	0.05	Bigelow et al. 1977
Stenonema pulchellum	0.21-.23	Trama 1972

TBMORT

79. TBMORT is the nonpredatory mortality rate for benthos (l/day). Leidy and Ploskey (1980), in their review of the literature, show most benthos nonpredatory mortality rates to be between 0.001 and a.02/day.

BEFFIC

80. BEFFIC is the assimilation efficiency for benthos (dimensionless). The assimilation efficiency is multiplied by the ingestion rate to obtain an assimilation rate. Values for benthos assimilation efficiency are given in Table 22.

Table 22

Benthos assimilation efficiencies (dimensionless)

SPECIES	VALUE	REFERENCE
Anatopina dijari	0.30	Teal 1957
Asellus aquaticus	0.30	Klekowski 1970
Asellus aquaticlls	0.26-0.44	Prus 1971
Bandsiola crotchii	0.31-0.40	Winterbourn 1974
Calopsectra dives	0.20	Teal 1957
Carnivores	0.20-0.97	Lawton 1970
Gammarus pseudolimnaeus	0.10-0.20	Barlocher and Kendrick 1975
Gamrnarus pseudolimnaeus	0.42-0.75	Barlocher and Kendrick 1975
Gammarus pseudolimnaeus	0.10	Marchant and Hynes 1981
Gammarus pulex	0.30-0.40	Nilsson 1974
Glossosoma nigrior	0.17-0.32	Cummins 1973
Hedriodiscus	0.59	Stockner 1971
Hyalella azeteca	0.05-0.80	Hargrave 1970
Hydrophilus triangularis	0.55	Hallmark and Ward 1972
Lepidostoma	0.07-0.12	Grafius 1973
Lestes sponsa	0.36	Klekowski et al. 1970
Lethocerus americanus	0.07	Guthrie and Brust 1969
Limnodrilus hoffmeisteri	0.5	Teal 1957
Most invertebrates	0.5	Monakov 1972
Potamopyrgres jenkinsi	0.04	Heywood and Edwards 1962
Potomophylax cingulatus	0.10-0.30	Otto 1974
Pteronarcys scotti	0.11	McDiffett 1970
Pyrrhosoma	0.77-0.91	Lawton 1970
Simulium	0.57	McCullough 1975
Stenonema	0.52	Trama 1957
Tricorythodes minutus	0.07-0.55	McCullough 1975
Tubifex tubifex	0.5	Ivlev 1939

BS2SED

81. BS2SED is the half-saturation coefficient for benthos feeding on organic sediment (g/m^2). Leidy and Ploskey (1980), after a thorough review of the literature, wrote that they were unable to find a single reference that documented, in units convertible to carbon, the change in benthic grazing as a function of food concentration. In addition, the value of the coefficient depends on the depth of the sediment being modeled, which is itself a variable. The authors of the present report recommend using values slightly smaller than half the initial condition for the sediment, which is reported in g/m^2.

TBRESP

82. TBRESP is the maximum respiration rate for benthos (l/day). Respiration rates are estimated directly by monitoring benthic oxygen consumption by manometric, chemical, or polarographic methods. Values for the respiration rate for benthos are given in Table 23.

Table 23

Maximum respiration rates for benthos II/day)

SPECIES	TBRESP	TEMP ·C	REFERENCE
Acartia	0.129-.215	NA"	Williams 1982
Ancylus f1uviati1is	0.035-.049	,•	Berg 1952
Baetes sp.	0.47-.72	10	Fox et al. 1937
Bithynia tentacu1ata	0.020	13	Berg & Ockelmann 1959
Bithynia 1eachi	O.031	13	Berg & Ockelmann 1959
Chironomus anthracinus	0.005	11	Berg et al. 1962
Chironomus strenzkei	0.12-.14	30	Plpatzer-Schu1tz 1970
Ch1oeon dipterum	0.16-.46	10-16	Fox and Simmonds 1933
Coenis 5p.	0.075	10	Fox et a1. 1935
Corethra f1avicans	0.002	11	Berg et al. 1962
Corycaeus	0.051-.270	NA	Williams 1982
Echyonurus venosus	0.17-.34	10	Fox et al. 1935
Ephemera simulans	0.063	20	Olson and Rueger 1968
Ephemera vu1gata	0.072-.19	10	Fox et al. 1935
Ephemera damica	0.095-.21	10	Fox et a1. 1935
Ephemere11a ignita	0.24	10	Fox et al. 1935
Erpobdella oculata	0.034	20	Mann 1956
Erpobdel1a testacea	0.052	20	Mann 1956
Gammarus pulex	0.10-.12	NA	Fox and Simmonds 1933
Gastropoda, Veliger	0.107	NA	Williams 1982
G1ossiphonia comp1anata	0.044	20	Mann 1956
He1obdel1a stagnalis	0.052	20	Mann 1956
Ilyodrilus hammoniensis	0.0009	11	Berg et al. 1962
Larvaceans	0.014-.043	NA	Williams 1982
Lumbricil1us riva1is	0.006	11	Berg et al. 1962
Lymnaea aricu1aria	0.016	13	Berg & Ockelmann 1959
Lymnaea palustris	0.027	13	Berg & Ockelmann 1959
Lymnaea pereger	0.023	13	Berg & Ockelmann 1959
Many groups	0.0001-.04	NA	Olson and Rueger 1968
Myxas glutinosa	O.026	13	Berg & Ocke1mann 1959
Oligotrichs	0.257	NA	Williams 1982
Physa fontina1is	0.041	13	Berg & Ockelmann 1959
piscico1a geometra	0.088	20	Mann 1956
Procladius sp.	0.002	11	Berg et al. 1962
Tintinnids	0.245	NA	Williams 1982
Tubifex barbatus	0.005	11	Berg et al. 1962
Tubifex tubifex	0.001	11	Berg et al. 1962
Va1vata piscinalis	O.041	13	Berg & Ocke1mann 1959

* NA = not available.

BENT1, BENT2, BENT3, BENT4

83. Values for benthos temperature coefficients are given in Table 24.

a. BENT1 is the lower temperature bound at which metabolism continues to occur; it is usually 0 °C.
b. BENT2 is the lowest temperature at which processes are occurring near the maximum rate.
c. BENT3 is the upper temperature bounding the range of maximum rates.
d. BENT4 is the upper lethal temperature.

Table 24

Temperature coefficients for benthos metabolism (°C)

SPECIES	BENT1	BENT2	BENT3	BENT4	REFERENCE
Asellus aquaticus	0	15	NA*	NA	Moore 1975
Gammarus pulex	0	18	NA	NA	Moore 1975
Gammarus pseudolimnaeus	0	20	NA	NA	Marchant & Hynes 1981

* NA not available.

Fish

84. CE-QUAL-R1 has three fish compartments for simulating piscivorous, planktivorous, and benthic-feeding assemblages in a reservoir. Since many fish species are omnivorous, however, the weighting procedure for computing composite compartment rates is different from other compartments. A report by Leidy and Jenkins (1977) provides all the information necessary to compute the required composite rate coefficients.

85. In the model, the piscivorous fish (compartment 1) feed only on the other two fish compartments. Fish in the second compartment feed on detritus, zooplankton, and the two algal groups; fish in the third compartment feed on

sediment and benthos.

TFMAX

86. $TFMAX_{,1}$ is the maximum ingestion rate (l/day) for the piscivorous fish compartment. The composite rate for the compartment should be computed based on the mean annual standing crop estimate. Ingestion rates vary as a function not only of species, but also of other factors such as condition or age class; the ingestion rate should reflect these factors by using, for example, average age class estimates.

87. $TFMAX_{,2}$ is the maximum ingestion rate for planktivorous fish (l/day). The planktivorous fish consume zooplankton, algae, and detritus.

88. $TFMAX_{,3}$ is the maximum ingestion rate for benthic fish (1/day). Benthic-feeding fish ingest both benthos and organic sediment.

89. In general, a TFMAX coefficient of 0.01 represents maintenance without growth; 0.04 to 0.05 represents optimum growth efficiency (Leidy and Jenkins 1977).

FS2BEN, FS2Z00, FS2FSH

90. To adjust the ingestion rate of fish due to the available food supply, the fishery model uses half-saturation constants; these represent the amount of food present that results in fish ingestion at half the maximum growth rate. It has been suggested that the half-saturation constant be considered to be 5 percent of fish wet body weight consumed per day at 20°C (Leidy and Jenkins 1977). Five percent of the body weight consumed per day corresponds closely with the food intake rate for optimum efficiency in growth (4 to 5 percent for many species). User's of CE-QUAL-Rl should refer to Leidy and Jenkins (1977) because

of the difficulty in estimating half-saturation coefficients. Estimates of fish half-saturation coefficients are given in Table 25.

a. FS2BEN is the benthic-feeding fishes' (FISH3) half-saturation coefficient for benthos and sediment grazing (mg/L).
b. FS2Z00 is the planktivorous fishes' (FISH2) half-saturation coefficient for zooplankton, detritus, and algae (mg/L).
c. FS2FSH is the piscivorous fishes' (FISHl) half-saturation coefficient for feeding on FISH3 and FISH2 (mg! L).

Table 25

Estimated half-saturation coefficients for fish growth (mg!LI
(from Leidy and Jenkins 19771

SPECIES	FOOD TYPE	VALUE	REFERENCE
Largemouth bass	minnows	'.6	Thompson 1941
Smallmouth bass	minnows	7.2	Williams 1959
Muskellunge	minnows	5.6	Gammon 1963
Reticulate sculpin	midge larvae	•••	Davis and Warren 1965
Sockeye salmon	mixed diet	3.9-7.9	Brett et al. 1969
Channel catfish	mixed diet	3.1	Andrews and Stickney 1972

F2ALG, F2DET, F2Z00, F3BEN, F3SED

91. Preference factors for fish compartments 2 and 3 are as follows:

a. F2ALG is the preference of FISH2 for algae (dimensionless).
b. F2DET is the preference of FISH2 for detritus (dimensionless).
c. F2Z00 is the preference of FISH2 for zooplankton (dimensionless).
d. F3BEN is the preference of FISH3 for benthos (dimensionless).
e. F3SED is the preference of FISH3 for sediment (dimensionless).

Information relating to fish preference factors is supplied in Leidy and Jenkins (1977) and is reprinted here in Table 26 below. Unfortunately, the different fish foods are expressed as fractions of the total diet rather than as quantities (i.e. grams) consumed, making preference factors difficult to estimate from this information.

Table 26

Fish food expressed as a fraction of the diet (from Leidy and Jenkins 1977)

SPECIES	PLANT	DETRITUS	ZOOPL	BENTHOS	FISH
Gizzard shad	0.10	0.80	0.05	0.05	
Threadfin shad (young)	0.30	0.50	0.10	0.10	
Threadfin shad (old)	0.30	0.05	0.15	0.55	0.10
Rainbow trout	0.05		0.60	0.15	
Brook trout			0.90	0.05	
Carp	0.30	0.40	0.20	0.10	
Minnows	0.20		0.20	0.60	
Carpsuckers	0.15	0.65	0.05	0.15	
Suckers	0.15	0.65	0.05	0.15	
Hogsuckers		0.80	0.05	0.15	
Buffalofish	0.05	0.40	0.05	0.15	
Redhorse			1.00		
Bullhead	0.10	0.25	0.50		0.15
Catfish	0.27	0.10			0.80
Madtoms			0.55		0.18
Silversides			0.20	0.80	
Temperate bass			0.20	0.10	0.70
Sunfish	0.10	0.05	0.65		0.05
Black bass			0.08		0.86
Crappie	0.05	0.05	0.20	0.15	0.55
Perch			0.20	0.20	0.60
Freshwater drum		0.08	0.58		0.34

92. An example is given for calculating preference factors for the third fish compartment when actual quantities consumed are known. Suppose a particular species of fish consumes 2 9 out of an available 16.0 9 of benthos and 0.26 9 out of an available 120.0 9 of sediment. The preference factor (P) for the ith food category equals

$$Pi = (Ei/Ai)/SUMi(Ei/Ai» \quad (22)$$

where

Ei = the amount of the ith food consumed

Ai = the amount of the ith food available

For the above examples the preference factors would be

P(benthos) = (2.0/16.0)/0.127166 = 0.983

P(sedirnent) = (0.26/ 120.0)/0.127166 = 0.017

FSHT1, FSHT2, FSHT3, FSHT4

93. Upper and lower temperature tolerances for fish ingestion are presented as follows:

a. FSHTl is the lower temperature boundary, usually 0 DC, at which metabolism continues.
b. FSHT2 is the lowest temperature at which processes are occurring at the maximum rates.
c. FSHT3 is the upper temperature bounding the range of maximum rates.
d. FSHT4 is the upper lethal temperature.

94. For most warmwater species, upper and lower temperature tolerances are similar, the lower limit being reached at DoC and the upper limit between 33 and 37°C; the optimum temperature is about 27°C. Coldwater species such as salmonids reach a lower temperature limit at DoC, but the upper limit is near 25°C; the optimum temperature is about 14°C. Temperature tolerance values and the various acclimation temperatures (ACCL), where available, are given in Table 27.

Table 27

Temperature coefficients for fish ingestion (Oe)
(from Leidy and Jenkins 1977)

SPECIES	ACCL	FSHT!	FSHT2	FSHT3	FSHT4	REFERENCE
Pickera1s		●		24	34.4	Leidy and Jenkins 1977
Minnows		●	27		33.4	Leidy and Jenkins 1977
Catfish		●	3.		37.1	Leidy and Jenkins 1977
Sunfish		2.5	27.5		35.7	Leidy and Jenkins 1977
Black bass		1.6	27		36.5	Leidy and Jenkins 1977
Crappie			23		32.5	Leidy and Jenkins 1977
Yellow perch		●	24.2		30.9	Leidy and Jenkins 1977
Yellow perch				29		Schneider 1973
Fingerling salmon			15			Brett et al. 1969
Bluntnose minnow	5				26.0	Hart 1947
Bluntnose minnow	,'				2B.3	Hart 1947
Bluntnose minnow	15	1..			30.6	Hart 1947
Bluntnose minnow	2.	4.2			31.7	Hart 1947
Bluntnose minnow	25	7.5			33.3	Hart 1947
Flathead minnow	,'				2B.2	Hart 1947
Flathead minnow	2.	1.5			31.7	Hart 1952
Flathead minnow	3.	10.5			33.2	Hart 1952
Creek chub	5				24.7	Hart 1952
Creek chub	,'				27.3	Hart 1952
Creek chub	15				29.3	Hart 1952
Creek chub	2.	..7			30.3	Hart 1952
Creek chub	25	4.5			30.3	Hart 1952
Chub	"				27.1	Black 1953
Finescaled sucker	14				26.9	Black 1953
White sucker	25				31.2	Brett 1944
White sucker	5				26.3	Hart 1947
White sucker	,'				27.7	Hart 1947
White sucker	15				29.3	Hart 1947
White sucker	2.	2.5			29.3	Hart 1947
White sucker	25	6.0			29.3	Hart 1947
White sucker			27			McCormick and Mischuk 1973
Brown bullhead	5				27.B	Hart 1952
Brown bullhead	,'				29.0	Hart 1952
Brown bullhead	15				31.0	Hart 1952
Brown bullhead	2.				32.5	Hart 1952
Brown bullhead	25				33.8	Hart 1952
Brown bullhead	3.				34.8	Hart 1952
Brown bullhead	34				34.8	Hart *1952*
Black bullhead	23				35	Black 1953
Channel catfish	25				35.5	Allen and Strawn 1968
Channel catfish	35				38	Allen and Strawn 1968
Channel catfish			18			Andrews and Stickney 1972
Channel catfish	15	●●●			30.3	Hart 1952
Channel catfish	2.	2.5			32.B	Hart 1952
Channel catfish	25	6••			33.5	Hart 1952
Bluegill	15	2.5			30.7	Hart 1952
Bluegill	2.	5••			31.5	Hart 1952
Bluegill	25	7.5				Hart 1952

Table 27 (concluded)

SPECIES	ACCL	PSHT1	FSHT2	FSHT3	PSHT4	REFERENCE
Bluegill	30	11.1			33.B	Hart 1952
Bluegill			22		33.B	McComish 1971
Longear sunfish	25				35.6	Neill et a1. 1966
Longear sunfish	30				36.B	Neill et a1. 1966
Longear sunfish	35				37.5	Neill et al. 1966
Pumkinseed	25				24.5	Brett 1944
Smal.lmouth bass	35	1..	26.3		35.0	Horning and Pearson 1973
Smallouth ba••			28.3			Peck 1965
Largemouth bass			27.5	30		Strawn 1961
Largemouth bass			25			Niimi and Beamish 1974
Largemouth bass	20	5.5			32.5	Hart 1952
Largemouth bass	25				34.5	Hart 1952
Largemouth bass	30	11.8			36.4	Hart 1952
Yellow perch	5				21.3	Hart 1947
Yellow perch	10	1.1			25.0	Hart 1947
Yellow perch	15				27.7	Hart 1947
Yellow perch	25	3.7			29.7	Hart 1947
Yellow perch-juvenile	24		20	23.3		McCauley and Read 1973
Yellow perch-adult	24		17.6	20.1		McCauley and Read 1973
Yellow perch	8		18.6			Ferguson 1958
Yellow perch	10		19.3			Ferguson 1958
Yellow perch	15		23.0			Ferguson 195B
Yellow perch	20		23.1			Ferguson 1958
Yellow perch	25		24.5			Ferquson 1958
Yellow perch	30		26.7			Ferguson 1958
Sockeye salmon-fry	5	0			22.2	Brett 1952
Sockeye salmon-fry	10	3.1			23.4	Brett 1952
Sockeye salmon-fry	15	4.1			24.4	Brett 1952
Sockeye salmon-fry	20	4.7			24.8	Brett 1952
Sockeye salmon-juvenile	15		15	17		Brett et al. 1969
Coho salmon	5	0.2			20.9	Brett 1952
Coho salmon	10	1.7			23.7	Brett 1952
Coho salmon	15	3.5			24.3	Brett 1952
Coho salmon	20	4.5			25.0	Brett 1952
Chinook salmon			18.4			Olson and Foster 1955
Northern pike	25				32	Scott 1964
Lake trout			11.7			McCauley and Tait 1970
Lake trout			8	10.9		Rawson 1961
Rainbow trout	18		17	20		McCauley and Pond 1971
Brook trout	5				23.7	Fry et al. 1946
Brook trout	10				24.4	Fry et al. 1946
Brook trout	15				25.0	Fry et al. 1946
Brook trout	20				25.3	Fry et al. 1946
Brook trout	25	0.5			25.3	Fry et al. 1946
Brook trout			14	19		Graham 1949

FEFFIC

95. FEFFIC, the assimilation efficiency for fish (dimensionless), ranges from 0.66 to 0.98; a value of 0.80 is realistic for most fish (Leidy and Jenkins 1977). The assimilation efficiency is multiplied by the ingestion rate to obtain an assimilation rate. Values for fish assimilation efficiency are given in Table 28.

Table 28

Assimilation efficiencies of fish (dimensionless)

SPECIES	FEFFIC	REFERENCE
Bleak	0.80	Mann 1965
Blueback herring	0.80	Burbridge 1974
Bluegill	0.80	Pierce and Wissing 1974
Bluegill	0.97	Gerking 1955
Carnivorous fish	0.80	Wingerg 1956
Carp	0.74	Ivlev 1939a
Carp	0.95	Kobashi and Deguchi 1971
Cichlasama bimaculatum	0.69-0.89	Warren and Davis 1967
Cutthroat trout	0.84-0.86	Krokhin 1959
Ctenopharyngodon	0.14	Fisher 1970
Dace	0.79	Mann 1965
Goldfish	0.71-0.86	Davies 1964
Green sunfish	0.94	Gerking 1952a
Longear sunfish	0.94-0.97	Gerking 1952a
Northern pike	0.72	Johnson 1966
Perea fluvatilis	0.35	Klekowski et a1. 1970
Perch	0.79	Mann 1965
Reticulate sculpin	0.74-0.84	Davis and Warren 1965
Roach	0.78	Mann 1965
White bass	0.66-0.69	Wissing 1974

TFMORT

96. TFMORT is the nonpredatory mortality rate for fish (l/day). Mortality rate is that fraction of fish biomass that is converted to detritus by death. Nonpredatory mortality rates can be highly variable depending on species, age, exploitation rate, and numerous environmental variables.

The average rate calculated by Leidy and Jenkins (1977) is 0.001 for exploited populations.

97. Ricker (1945) has reviewed techniques for calculating various mortality rates (total, instantaneous, conditional, natural, and fishing). Values for nonpredatory mortality are given in Table 29.

Table 29

Fish nonpredatory mortality rates (l/day)

SPECIES	TFMORT	REFERENCE
American shad	0.002	Walburg 1961
Bluegill	0.002	Patriarche 1968
Bluegill	0.0002	Gerking 1952b
Bluegill	0.001	Ricker 1945
Brook trout	0.001	Latta 1962
Brook trout	0.003-.004	Alexander and Shetter 1961
Brook trout	0.56-1.34	Hatch and Webster 1961
Brown bullhead	0.001	McCammon and Seeley 1961
Brown bullhead	0.001	Rawstran 1967
Channel catfish	0.001	Ricker 1958
Cutthroat trout	0.001-.002	Hansen 1971
Cutthroat trout	0.001	Ball and Cope 1961
Freshwater drum	0.001	Butler 1965
Largemouth bass	0.00037	Mraz and Threinen 1955
Longnase sucker	0.002	Geen et al. 1966
Northern pike	0.002	Groebner 1960
Northern pike	0.002	Johnson and Peterson 1955
Rock bass	0.002	Ricker 1947
Walleye	0.001	Olson 1957
White catfish	0.001	McCammon and Seeley 1961

TFRESP

98. TFRESP is the fish respiration rate *(l/day)*. There are three types of respiration that can be defined: (a) standard respiration--oxygen consumed in the absence of measurable movement (i.e., nonactive respiration, basal of resting metabolism), (b) routine respiration--rate of

oxygen consumption of fish showing normal activity, and (c) active respiration--maximum rate of oxygen consumption under continuous forced active respiration. It would appear that the best estimates of the rate of respiration for normal active fish are values for routine metabolism (i.e., type 2 above) (Winberg 1956). Values for fish respiration rate are given in Table 30.

Table 30

Fish maximum respiration rates (l/day)

SPECIES	TFRESP	TYPE	REFERENCE
Brown bullhead	0.001	routine	Beamish 1964
Brook trout	0.003	routine	Beamish 1964
Carp	0.001	routine	Beamish 1964
Lake trout	0.001	standard	Gibson and Fry 1954
Rainbow trout	0.002	standard	Florke et al. 1954
Salvelinus fontinalis	0.006-.024	standard	Madsen et al. 1977
Salvelinus fontinalis	0.019-.101	active	Madsen et al. 1977
Sockeye salmon	0.002	standard	Brett 1944
White sucker	0.002	routine	Beamish 1964

Other Coefficients

TDSETL

99. TDSETL is the detrital settling velocity (m/day). Detrital settling velocities vary from 0.001 to over 200 m/day depending on the detrital characteristics and reservoir hydrodynamics. Settling rates should be obtained from quiescent settling chamber studies because advective and turbulent forces in the mixed layer that can reduce settling in a reservoir are modeled separately. For most studies, settling velocities are in the range of 0.05 to 1.0 m/day.

Much higher values are often reported for fecal pellets, as shown in Table 20; however, such high settling coefficients may be questionable because they produce unrealistically low detritus values in the modeling studies. Values for detritus settling velocities are given in Table 31.

Table 31

Detritus settling velocities (m/day)

SOURCE	TDSETL	REFERENCE
Ceratium balticurn	9.0	Apstein 1910
Chaetoceros borealis	5.0	Apstein 1910
Chaetoceros didymus	0.85	Eppley et al. 1967b
Cricosphaera carterae	1.70	Eppley et al. 1967b
Ditylum brightwellii	2.0	Apstein 1910
Fecal pellets:		
Acartia clausii	116.0	Smayda 1971
Fecal pellets:		
Euphausia krohnii	240.0	Fowler and Small 1972
Fecal pellets:		
Euphausia pacifica	43.0	Osterberg et al. 1963
Fecal pellets:		
Pontella meadii	54.0-88.0	Turner 1977
Phaeodactylum tricornutum	0.02-.04	Riley 1943
Rhizosolenia herbetata	0.22	Eppley et al. 1967b
Stephanopyxis tunis	2.1	Eppley et al. 1967b
Tabellaria flocculosa	0.46-1.5	Smayda 1971
Tha1assiosira psuedonana	0.85	Hecky and Kilham 1974

DETT1, DETT2

100. DETT1 is the lower temperature boundary at which decomposition continues to occur. It is usually 0 °C.

101. DETT2 is the temperature at which decomposition occurs near the maximum rate. Temperature coefficients for decomposition are given in Table 32.

Table 32

Temperature coefficients for decomposition (°C)

SUBSTRATE OR SITE	DETT1	DETT2	REFERENCE
Pseudomonas fluorescens: natural substrate	0	25-30	Tison and Pope 1980
E. coli: natural substrate	0	37	Tison and Pope 1980
Glucose: Lake George, New York	0	25	Tison et al. 1980
Glucose	0	20-30	Bott 1975
Glucose: Lake Wingra, Wis.		25-30	Boylen and Brock 1973

TDOMDK

102. TDOMDK is the dissolved organic matter (DOM) decay rate (1/day). DOM in natural waters is the organic substrate for heterotrophic metabolism. The composition of natural DOM is highly variable and little understood, but its sources are generally grouped into (a) excretion from phytoplankton and macrophytes, (b) decomposition of phytoplankton and macrophytes, (c) excretion by animals, and (d) allochthonous drainage (e.g., humic compounds from upstream sources).

103. Aquatic bacteria appear to be chiefly responsible for the removal of DOM compounds from the water; they are the major agents for bacterial mineralization of organic solutes in fresh water (Wright 1975), using organic matter as an energy source. Various methods have been tested to determine the decay rate of DOM in water. Modification of the basic Parson and Strickland (1963) technique have been developed to quantify the kinetics.

104. DOM decomposition rates have also been represented by filtered carbonaceous biochemical oxygen demand (BOD) decay rates. If sufficient oxygen is available, the

aerobic biological decomposition of organics will continue until all the DOM is consumed. In the standard test for BOD, a sample is diluted with water containing a known amount of oxygen. The loss of oxygen after the sample has been incubated for 5 days at 20°C is known as the 5-day BOD. The value of the first-order decay rate is generally about 0.05 to 0.20 per day.

105. The BOD test suffers from several serious deficiencies. The test has no stoichiometric validity, for example: the arbitrary S-day period usually doesn't correspond to the point where all the organic matter is consumed.

106. Contributing to the errors involved in measuring decay rates of DOM is the extensive variability in the composition and stage of decomposition of DOM. Allochthonous inputs of DOH are likely to be more refractory than autochthonous inputs, and as a resu1t, decomposition rates will be slower and decay may be incomplete; therefore, the length of time the organic matter is available for decomposition is important. In addition, as particles sink out of the euphotic zone, both dissolved and detrital organic substrates may be limited to more resistant fractions thereby arresting attached microbial growth. Therefore, the rate of DOM decomposition may be lower in the hypolimnion of a stratified reservoir.

107. Oxygen consumption rate (mg 02/L/hr) can be transformed into a mineralization rate of organic carbon (mg C/L/hr) by application of a conversion factor of 0.29 (Seepers 1981). Values for DOM decay rate are given in Table 33.

Table 33

DOM decay rates (ljday)

COMPOUND	TDOMDK	REFERENCE
Acetate	0.2	Wright 1975
Amino acids	0.64	Williams et al. 1976
Glucose	0.24	Williams et al. 1976
Glucose	0.32-.50	Toerien and Cavari 1982
Glucose	0.111	Wright 1975
Glutamate	0.11-.625	Carney and Colwell 1976
Glycine	0.312-.45	Vaccaro 1969
Glycine	0.048	Vaccaro 1969
Glycolate	0.024-.432	Wright 1975
Glycolate	0.012-.25	Wright 1975
Glycolic acid	0.004	Tanaka et al. 1974

TNH3DK

108. TNH3DK is the ammonia decay rate (i.e., the rate at which ammonia is oxidized to nitrite) (l/day). Ammonia is generated by heterotrophic bacteria as the primary end product of decomposition of organic matter, either directly from proteins or from other nitrogenous organic compounds. Although ammonia is a major excretion product, this nitrogen source is minor in comparison to decomposition.

109. Nitrification is the biological conversion of organic and inorganic N compounds from a reduced state to a more oxidized state (Alexander 1965). The nitrifying bacteria capable of oxidation of NH_4^+ to NO_2^- are largely confined to the species Nitrosomonas, bacteria which are mesophilic (1-37 °C).

110. Nitrification rate can be determined by a number of different techniques. Courchaine (1968) has plotted nitrogenous BOD on a logarithmic scale and determined the decay rate from the slope of the line. Thomann et a1. (1971) used a finite-difference approximation to solve a

set of simultaneous linear equations.

111. Laboratory measurements for the ammonia decay rate can produce results that differ from what might be measured in situ. Several environmental factors influence the rate of nitrification, including pH, temperature, suspended particulate concentration, hydraulic parameters and benthos.

112. Nitrification can be measured as a one- or two-step process. In the one-step method, only the end product of the entire reaction, nitrate, *is* measured. In the two-step method, (a) nitrite accumulation *is* measured as ammonia is oxidized to nitrite and (b) nitrate accumulation is measured as nitrite is oxidized to nitrate. oxidation of ammonia to nitrite is the rate-limiting step in the total reaction; therefore, experiments that measure the rate of the total reaction (i.e., the one-step method) can be used to estimate this parameter. Ammonia oxidation rates are given in Table 34.

Table 34

Ammonia oxidation rates (l/day)

SITE	TNH3DK	REFERENCE
Wastewater treatment plant	0.05-0.30	Wild et al. 1971
Grand River, Ill.	0.80	Bansal 1976
Grasmere Lake, U.K.	0.001-.013	Hall 1982
Truckee River, Nev.	0.09-1.30	Bansal 1976
Upper Mohawk River, N.Y.	0.23-0.40	Bansal 1976
Middle Mohawk River	0.30	Bansal 1976
Lower Mohawk River	0.30	Bansal 1976
Ohio River	0.25	Bansal 1976
Big Blue River, Neb.	0.17-0.25	Bansal 1976
Flint River, Mich.	0.76-0.95	Bansal 1976

TN02DK

113. TN02DK is the decay rate of nitrite to nitrate (l/day).

TDETDK

114. TDETDK is the detritus decay rate (l/day). Detritus as defined by Wetzel et al. (1972) consists of organic carbon lost from an organism by nonpredatory means (including egestion, excretion, secretion, etc.) from any trophic level component, or input from sources external to the ecosystem that enter and cycle in the system (i.e., allochthonous organic carbon). For CE-QUAL-Rl, this should be considered to be particulate material only.

115. The rate of detritus decay can be determined by measuring the use of oxygen during decomposition, with results expressed as a first-order decay coefficient (k base e = mg oxygen used/mg/day). Many workers have measured rates of oxygen uptake by detritus, suggesting that oxygen uptake is related to the organic matter available for decomposition. Odum and de la Cruz (1967) and Fenchal (1970), for example, demonstrated an inverse relation between detritus particle size and oxygen consumption. Oxygen uptake is an integrative measure of all oxidative processes occurring in the sample, both chemical and biological: reducing substances are usually rapidly oxidized; respiration of the organisms associated with detritus is primarily bacterial, although algae, protozoa, and fungi may also contribute. Measurement of the oxygen uptake reflects the metabolism of communities of microorganisms involved in the decomposition of natural substances.

116. As a detrital particle decomposes with time, there is a decline in oxygen uptake accompanied by succession of communities of microorganisms; this decline occurs

as the matter changes from labile to refractory; refractory matter often accumulates in the sediment. Rates of decay are generally high initially and slow down as the material becomes refractory; the rate *is* influenced by temperature, detrital composition, and age of the detritus. Macrophyte communities are the primary source of detritus in most systems. Submersed and floating macrophytes generally decay more rapidly than the highly lignified emergent species. Particulate organic matter of dead bluegreen algae decomposes much faster than that derived from green algae diatoms and desmids. Particulate organic matter (POM) is especially resistant (Gunnison and Alexander 1975). As detritus decays, there is a decrease in the C:N ratio as a result of a buildup of microbial protein (Mann 1972). A 1-g sample of detritus at 20°C consumes about 1 mg oxygen/hr (Hargrave 1972).

117. Plant litter consists of a variety of compounds *(i.e.,* sugars, hemicellulose, lignin, waxes) which decay at different rates. The decay curves initially tend to follow the exponential decay functions of the more readily degradable fractions, particularly aquatic macrophytes, which account for a large proportion of the weight of plant litter; therefore, the majority of the litter's weight loss occurs in the first year. Over the long term, the decay rates change, especially for deciduous leaf litter which has a larger proportion of decay-resistant material than do aquatic macrophytes and therefore decays at a much slower rate.

118. Decay rates can also be measured by suspending a nylon mesh bag of detrital material <u>in situ</u> or under controlled conditions and determining weight loss with time. This actually measures weight loss due to enzymatic decomposition by bacteria and fungi, solution of soluble sub-

stances, and loss of fragments through the container pores.

119. Decay rates have also been determined by measuring the mineralization rates of carbon, nitrogen, and phosphorus (Otuski and Hanya 1972). Decomposition of detritus generated from planktonic communities of surface lake water occurs at rates on the order of 10 percent per day (Saunders 1972), based upon radioactive carbon tracer studies.

120. Consideration should be given to the primary or expected sources of detritus. Decomposition rates for allochthonous detrital sources are generally lower than for autochthonous sources to reflect the more refractory nature of allochthonous material after its transport through the upper portions of the reservoir. While a one-dimensional model like CE-QUAL-Rl assumes instantaneous dispersal of inflow constituents, much of the decomposition in the prototype reservoir system occurs in the headwater area. The labile fraction of autochthonous detritus produced in the pelagic zones of the lower reservoir will decompose more rapidly in the water column and should have a higher decomposition rate than allochthonous detritus. However, in a stratified reservoir the POM in the hypolimnion may not be exchanged with the epilimnetic waters. The POM becomes more refractory with time, and rates of decomposition decrease.

121. Microbial decomposition of detritus can be represented by three stages: a very quick solution of soluble organic components, a relatively rapid decomposition of labile organic constituents, and slow decomposition of refractory organic constituents. Detritus decay rates are given in Table 35.

Table 35

Detritus decay rates (l/day)

DETRITUS SOURCE	TDETDK	REFERENCE
Beech	0.001-.004	Hanlon 1982
Cladophera glornerata	0.007	Piecznska 1972
Dead green algae	0.016-.076	Otsuki and Hanya 1972
Dead mixed algae	0.007-.111	Jewell and McCarty 1971
Dead mixed algae	0.007-.06	Fitzgerald 1964
Gloeotrichia echinulata	0.001-.007	Piecznska 1972
Isoetes lancustris	0.003-.015	Hanlon 1982
Leaf packs	0.005-.017	Sedell et al. 1975
Osier	0.001-.005	Hanlon 1982
Potamogeton crispus	0.002-.004	Rogers and Breen 1982
Potomogeton perfoliatlls	0.002-.007	Hanlon 1982

TCOLDK

122. TCOLDK is the coliform decay rate (l/day). Estimates of coliform die-off rates may be obtained in the laboratory or in situ. In situ, where there are no flow regime data, or where flows are of a transient nature, a commonly used method is to add a slug of a conservative tracer substance (a dye, rare element, or radioisotope) to steady-state discharge. The discharge plume is sampled, dilution is estimated from the concentration of tracer, and the decay rate *is* estimated from the dilution-corrected coliform counts. *This* technique gives misleading results in cases where the tracer is diluted by water heavily contaminated with the same discharge. Since the tracer was introduced as a slug, there is no way to know how many of the surviving coliforms originated in the tracer-dosed effluent and how many came from pre- or post-dosing effluent. This problem is reduced where the flow regime is sufficiently stable (Zison et a1. 1978).

123. There are two approaches to estimating die-off rates. Frost and Streeter (1924) were able to estimate the die-off rate using seasonal averages of coliform counts from a downstream station, by assuming plug flow in the river. Errors in the rates determined by this approach are attributable to (a) dilution and to longitudinal mixing that produced overestimates and (b) unconsidered sources of coliforms that produced underestimates.

124. In a second approach, a mathematical model of the flow and mixing in the system is used to correct the measurements for the effects of dilution. In this manner Marais (1974) analyzed coliform die-off in wastewater maturation ponds as a first-order decay reaction in a series of completely mixed steady-state reactors. Errors in the decay rates determined in this way are primarily attributable to the reliability of the system model.

125. Table 36 gives decay rates for coliform and fecal streptococcus. In Table 37 from Mitchell and Chamberlain (1978), the median die-off value was O.040/hr for freshwater coliform. In general, the die-off follows first-order decay kinetics, although a significant increase in coliform levels is commonly observed in the first several miles downstream from the outfall.

126. Factors affecting coliform decay rate include sedimentation, solar radiation, nutrient deficiencies, predation, algae, bacterial toxins, and physiochemical factors.

Table 36

Coliform and fecal streptococcus decay rates (l/day)

SPECIES	TCOLDK	REFERENCE
Fecal coliform	0.048-.096	Evans et ala 1968
Fecal streptococci	0.063	Evans et ala 1968
Fecal streptococci	0.004-.013	Geldreich et al. 1968
Total coliform	4.48-5.52	Kittrell and Furfari 1963
Total coliform	0.199-.696	Klock 1971
Total coliform	1.99	Marais 1974
Total coliform	0.168-1.56	Geldreich et ala 1968
Total coliform	0.009-.028	Klock 1971
Total coliform	0.021-.038	Evans et al. 1968
Total coliform	0.045-.049	Frost and Streeter 1924
Total coliform	0.024-.105	Hoskins et al. 1927
Total coliform	0.48-2.04	Mitchell and Chamberlain 1978

Table 37

Freshwater die-off rates of coliform bacteria measured in situ (l/da)
from MItC e an Chamber a1n 97

SITE	TEMP/SEASON	RATE	REFERENCE
Ohio River	Summer 20·C	1.175	Frost and Streeter 1924
Ohio River	Winter 5·C	*1.08*	Frost and Streeter 1924
Upper Illinois River	June-Sept.	2.04	Hoskins et al. 1927
Upper Illinois River	OCt.-Hay	2.52	Hoskins et al. 1927
Upper Illinois River	Dec. Mar.	0.576	Hoskins et al. 1927
Upper Illinois River	Apr.-Nov.	1.032	Hoskins et al. 1927
Lower Illinois River	June-Sept.	2.04	Hoskins et al. 1927
Lower Illinois River	Oct.-May	*0.888*	Hoskins et al. 1927
Lower Illinois River	Dec.-Mar.	*0.624*	Hoskins et a1. 1927
Lower Illinois River	Apr.-Nov.	*0.696*	Hoskins et al. 1927
Shallow turbulent stream	Summer	15.12	Kittrell and Koschtltzky 1947
Missouri River	Winter	*0.48*	Kittrell and Furfari 1963
Tennessee River (.Knoxville)	Summer	1.03	Kittrell and Furfari 1963
Tennessee River (Chattanooga)	Summer	1.32	Kittrell and Furfari 1963
Sacramento River, Calif.	Summer	1.752	Kittrell and Furfari 1963
Cumberland River, Md.	Summer	5.52	Kittrell and Furfari 1963
Groundwater stream	10·C	0.504	Wuhrmann 1912
Leaf River, Miss.	NA	0.408	Mah10ch 1974
Wastewater lagoon	7.9-2S.S·C	0.199-.696	Klock 1971
Maturation ponds	N'	1.99	Marais 1974
Maturation ponds	19·C	1.68	Marais 1974
Oxidation ponds	20·C	2.59	Marais 1974

TSEDDK

127. T5EDDK is the organic sediment decomposition rate (l/day). While sediment consists primarily of settled organic detritus, the decomposition rate should reflect the changing nature of the detritus as it reaches the sediment; i.e., it becomes more refractory since the labile portion of the organic detritus decomposes as it settles through the water column. In addition, since the initial value for sediment is in $91m^2$, the thickness of the sediment layer, along with TSEDDK, will affect the amount of predicted decomposition. Thus, if high initial values are used for sediment, TSEDDK may have to be lowered since only the top few centimeters of sediment are usually involved in aerobic decomposition. Hargrave (1969) found the following relationship between the rate of oxygen comsurnption by sediments (ml $02/m^2/hr$) and the temperature (T, °C):

$$\ln (02 \text{ consumption rate}) = 1.74*\ln(T)-1.30 \qquad (23)$$

At 6° C this would be 214.3 mg $02/m^2/day$, assuming a constant rate for the day and the conversion formula found in the CE-QUAL-Rl User's Manual (Environmental Laboratory 1982, p. 188). At 25· C the rate would be 2567 $mg/m^2/aay$. The amount of sediment (in mg/m^2) times the value for TSEDDK times 1.4 (i.e., the stoichiometric equivalent of oxygen uptake to sediment decay) should be near the 6-25 °C range.

DOMTl, DOMT2

128. DOMTl, the critical low temperature for DOM decay, is usually 0 °e.

129. DOMT2 is the optimum temperature for DaM decay (ee). Temperature coefficients for DaM decay are given in Table 38.

Table 38

Temperature coefficients for DOM decay (Oe)

SUBSTRATE	DOMTI	DOMT2	REFERENCE
Glucose	5.0	35.5	Toerien and Cavari 1982
Glucose: Lake George, N.Y.	0	25	Tison et al. 1980
Glucose	0	20-30	Batt 1975
Glucose: Lake Wingra, Wis.	0	25-30	Boylen and Brock 1973

NH3T1, NH3T2

130. Researchers have generally found temperature to affect nitrification rates, especially in the range of 10 to 35°C.

a. NH3Tl is the lower temperature boundary at which ammonium nitrification continues. It is generally 0 °C.
b. NH3T2 is the optimum temperature for oxidation of NH_3-N. The optimum temperature for nitrification is generally accepted to be between 25 and 30°C.

Temperature factors for ammonia oxidation are given in Table 39.

Table 39

Temperature coefficients for ammonia oxidation (Oe)

SPECIES OR SITE	NH3Tl	NH3T2	REFERENCE
Nitrosomonas	5	30	Knowles et al. 1965
Wastewater treatment plant	5	25	Wild et al. 1971
Ann Arbor, Michigan	2	20	Borchardt 1966

NO2T1, NO2T2

131. NO2T1 is the lower temperature boundary at which nitrate nitrification occurs (°C).

132. NO2T2 is the lowest temperature (°C) at which the oxidation of nitrite to nitrate occurs near the maximum rate.

TSSETL

133. TSSETL is the suspended solids settling velocity (m/day). The settling rate is dependent on the type of particle, grain size, density, temperature, viscosity, and turbulence. Most of the larger particles entering a reservoir settle very quickly and should not be included in the inflow. Lane (1938) gives figures of 0.86 to 860.0 *m/day* for particle diameters of 0.002 to 0.1 mm. Particles found in the main body of a reservoir are usually at the lower end of this scale.

Q10COL

134. CE-QUAL-R1 uses a Q10 formulation to modify the coliform die-off rate as a function of temperature. All other rates are modified by temperature through the RMULT function in CE-QUAL-R1. The Q10 coefficient is usually 1.04.

PART III: RECOMMENDATIONS

135. This report provides information about, and values for, many of the coefficients needed for use of the version of the model CE-QUAL-R1 described in the User's Manual (Environmental Laboratory 1982).

136. Research on processes described in this report is likely to provide more information needed to refine the equations used in the model. Future versions of the model may therefore require additional coefficients.

137. This report may be updated to provide information about, and values for, any additional coefficients needed for use of future versions of the model.

138. Application, calibration, and verification of the model to a variety of sites is likely to identify coefficient values that are best suited to the model. These values may be included in updates to this report.